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12

A view of the Nazionale Cogne four-stand looping mill at Aosta. Three of the eight loops are controlled by Asea loop regulators. (F 565)

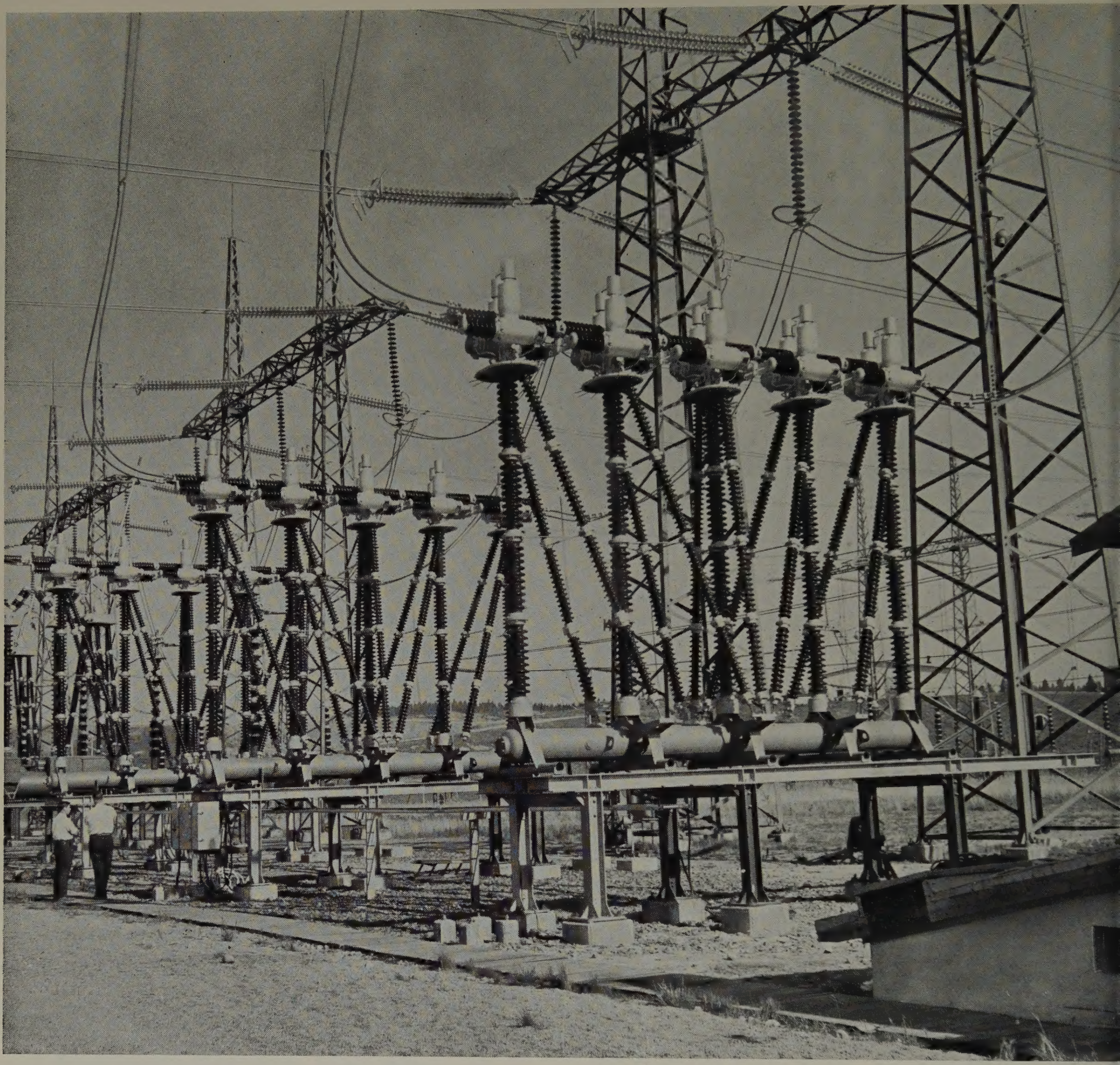
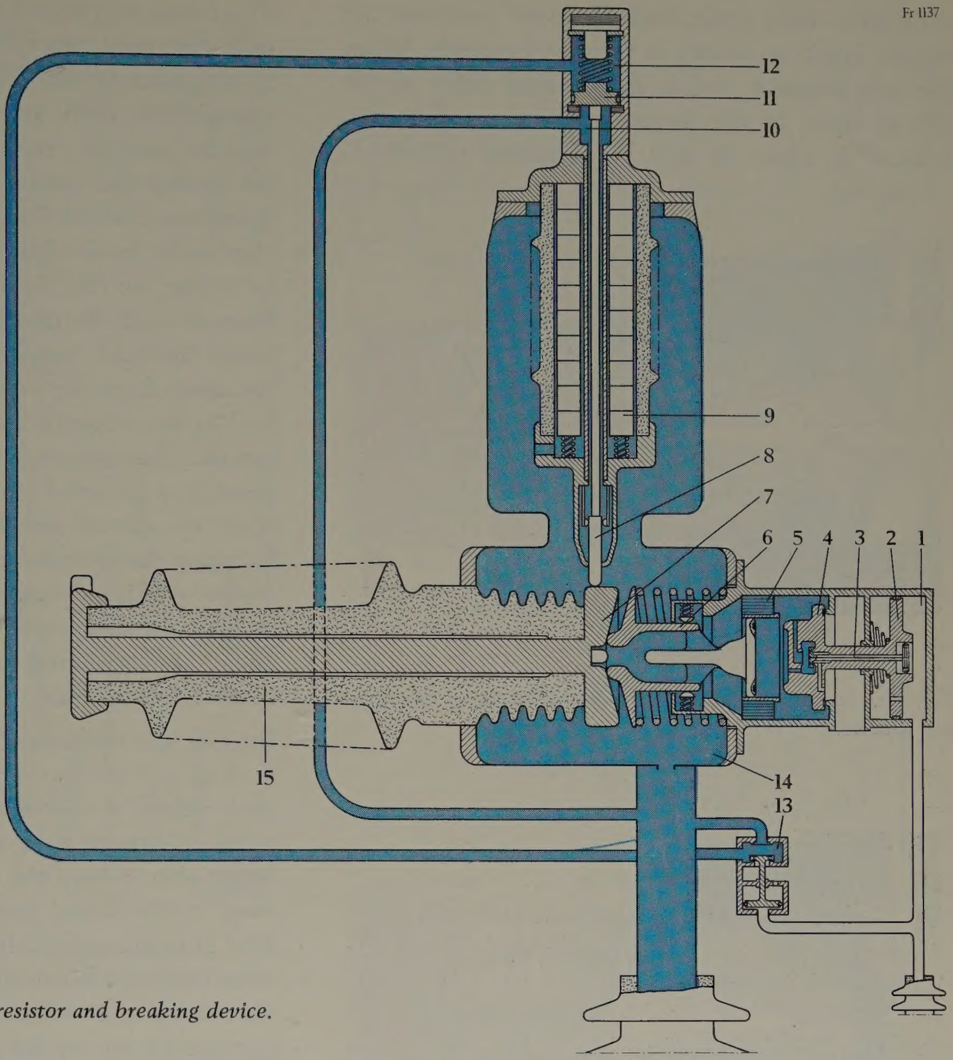


Fig. 1. Air-blast circuit-breaker HVH 420/1610 set up for testing at Kilforsen. (53047)

1. Breaking of a 100–700 km (62–435 mile) line under no-load at a voltage of 550 kV before breaking and a supply-frequency voltage of 400 kV on the input side immediately after breaking: $k_{max}=2.5$.
2. Breaking of a 100–700 km (62–435 mile) line, the far end of which is loaded with a transformer under no-load or with a transformer loaded with reactors at service voltages up to 420 kV: $k_{max}=3.3$.
3. Breaking of a transformer under no-load with a rated output of up to 600 MVA at voltages up to 420 kV: $k_{max}=3.3$.
4. Breaking of a transformer with a rated output of up to 600 MVA loaded with reactors having outputs between 40 and 180 MVA at voltages up to 420 kV: $k_{max}=3.3$. If the same "over-voltage level" is permitted as in case 1, then $k=2.5\times550/420=3.3$.

At the request of Asea, the breaking of a line under no-load was repeated with a circuit-breaker having a reduced number of breaks. The reason for this was that at certain points in the network, it is sufficient to have a reduced breaking capacity and, with it, a smaller number of breaks as well as a less even voltage distribution between the breaks.

Within recent years the regulations quoted above concerning the maximum permitted over-voltage factor have been discarded and replaced by a requirement that the power circuit-breakers are to be free from restriking when breaking a 100–700 km (62–435 mile) line under no-load at voltages up to 550 kV before breaking. In the case of transformer breaking, the lightning arresters are regarded as being able to give adequate protection without being damaged themselves, for which reason no regulations as to the magnitude of the over-voltages have been prescribed for this type of breaking.



1 Operating cylinder
2 Piston
3 Pilot valve
4 Main valve disc
5 Cooler
6 Moving contact
7 Fixed contact
8 Moving resistor contact
9 Resistor
10 Air-duct
11 Piston for resistor contact
12 Operating cylinder
13 Valve
14 Pressure chamber
15 Bushing

Fig. 2. Complete interruptor with resistor and breaking device.

DESCRIPTION OF THE CIRCUIT-BREAKER TESTED

The main data for air-blast circuit-breaker HVH 420/1610 are as follows:

Rated service voltage	420 kV
Rated service current	1,600 A
Rated pressure	15 atm gauge (215 lb/sq.in.)
Number of power breaks per phase	10
Rated breaking capacity at 420 kV and P.F. < 0.15 (inductive):	
Symmetrical breaking current (corresponding to 15,000 MVA)	20.6 kA
Asymmetrical breaking current	26.2 kA
Opening time	< 0.048 s

Fig. 1 shows a circuit-breaker at the test site in the 400 kV switchyard at Kilforsen. The circuit-breaker has 10 power breaks connected in series per pole, and each break is enclosed in a pressure chamber which is normally filled with compressed air. An interruptor, which comprises a break of this kind with its appropriate grading resistor and resistor break is shown in Fig. 2. The circuit-breaker has no series isolator and the permanent dielectric strength in the open position is provided by the breaks which remain open and under pressure. The voltage is controlled during the breaking sequence by means of grading resistors with comparatively low resistance, thus also providing protection against over-voltages when breaking small inductive currents. The resistors with their appropriate breaks are located in the same chamber as the power breaks. The resistors are disconnected about 25 ms after the power breaks have opened and then voltage control is carried out with the aid of capacitors. The arrangement of the capacitors can be seen from Fig. 1 where it is possible to distinguish the porcelain insulators of the capacitors placed parallel to the bushings of the power breaks.

The mode of operation of the circuit-breaker can be seen from Fig. 3. As has been mentioned previously, Fig. 2 shows a complete interruptor with grading resistor and resistor break. Both the power break and the resistor break are shown in the closed position. When the circuit-breaker opens, an operating valve in the bottom frame of the circuit-breaker opens and compressed air comes up into the operating cylinder 1.

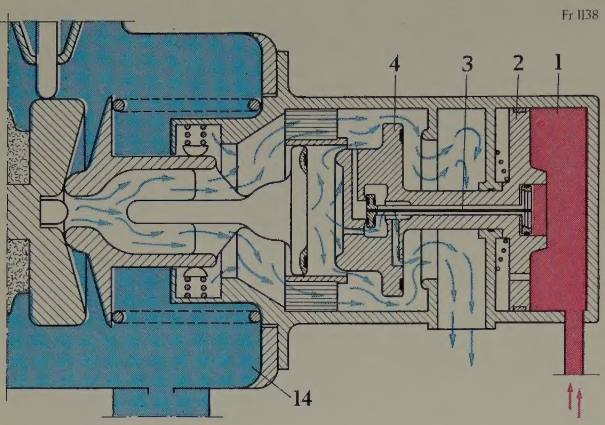


Fig. 3 a. Breaking element during the beginning of the opening process.

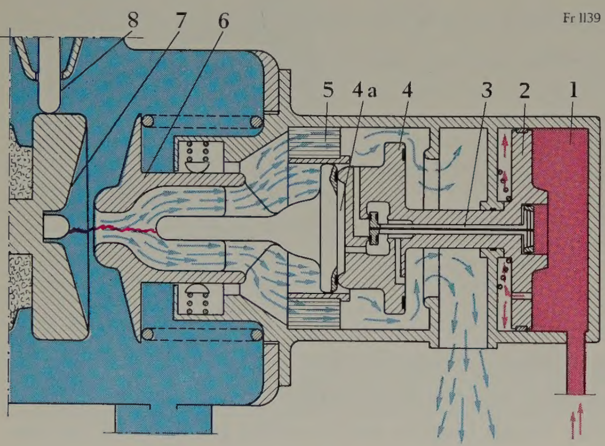


Fig. 3 b. Breaking element during arc extinction.

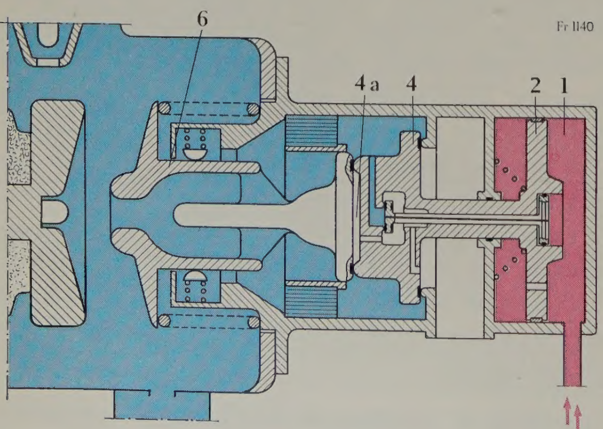


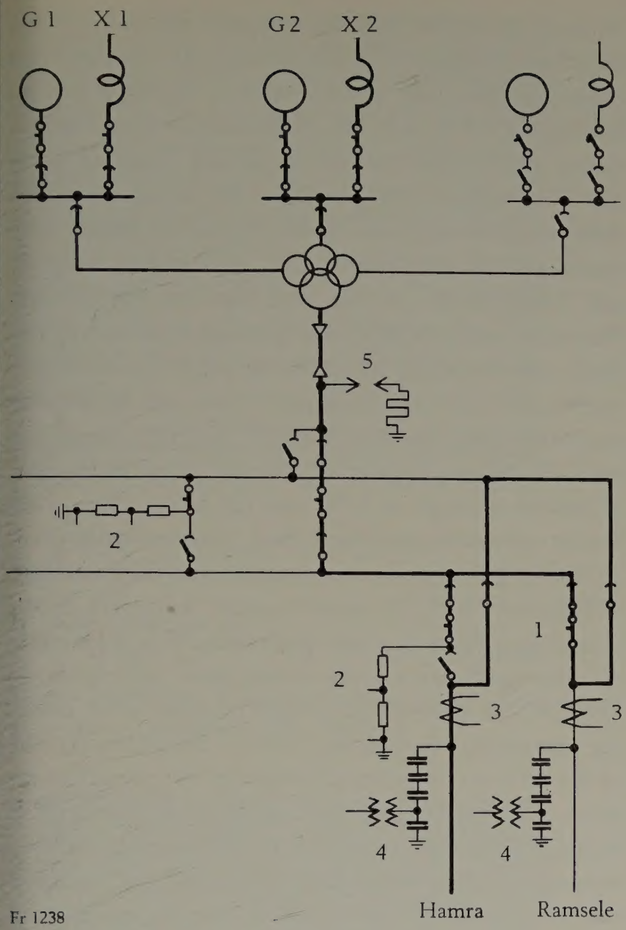
Fig. 3 c. Breaking element in open position.

This forces the piston 2 to the left, see Fig. 3a, wher upon the main valve disc 4 opens. The pilot valv 3 also moves to the left and opens a channel runnin through the main valve disc between the pressu chamber and the ambient air. When the air pou out through the opening freed by the main valve disc the pressure behind the moving contact 6 drops, and th then moves to the right until it is stopped by the mai valve disc, see Fig. 3b. If, during this sequence, curre flows through the circuit-breaker, an arc is drawn between the fixed contact 7 and the moving contact Air flows from the pressure chamber 14 through th hole in the moving contact, through the cooler 5 an out past the open main valve disc. The arc is thus exposed to a powerful stream of air and is extinguishe when the current goes through zero. In this positio known as the extinguishing position, Fig. 3b, the movin contact remains stationary only during the short perio which is required to ensure that the arc is extinguished After this, the moving contact continues its movemen in the following way.

Because the compressed air in the cylinder 1 passe through the hole in the piston 2 and gradually fills th space behind the piston and levels out the difference i pressure between these two spaces, the piston 2 is n longer able to keep the main valve disc open. This returns to the closed position and thus stops the outflow of compressed air from the pressure chamber. Th main valve disc is followed in the closing movement b the moving contact because of the fact that atmospheri pressure obtains in the space 4a. This is because th pilot valve maintains its position as long as the space is under pressure. The power break is now in the completely open position, Fig. 3c, and the compressed ai between the contacts 6 and 7 has adequate dielectri strength to withstand the dielectric stresses which ca arise across the circuit-breaker in the open position.

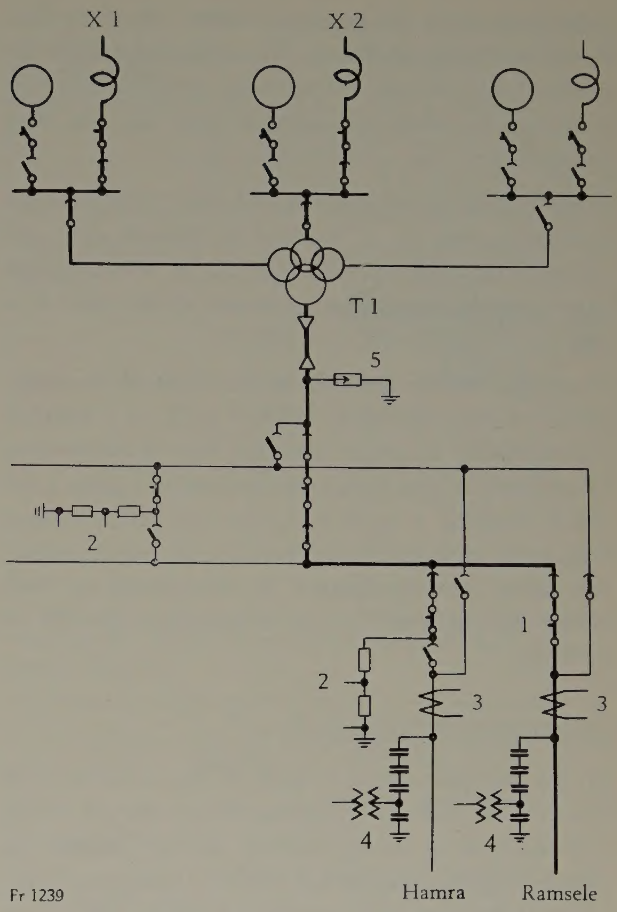
While the sequence described here is going on, th valve 13, which has been supplied with compressed ai at the same time as the space 1, has changed position As a result, the air in the space 12 in the resistor devic is exhausted, whereupon the piston 11, under the influence of the pressure in the air-duct 10 which i connected with the supply duct to the pressure chamber 14, moves upwards. The operating rod mounted o the piston 11 moves in unison and opens the contact of the resistor break, whereupon resistor 9 is disconnected. Before this disconnection has taken place, bu after the contact 6 of the power break has opened, a will be seen from Fig. 3b, the resistor 9 is in parallel wit the power break and then serves as a grading and protective resistor.

When the breaks are closed, the space 1 is emptie through the previously mentioned operating valve in th



1 Circuit-breaker under test
2 Voltage-divider
3 Current-transformer
4 Voltage-transformer
5 Rod-gap

Fig. 4 a. Testing system for interruption of an unloaded, and reactively loaded, transmission line.



1 Circuit-breaker under test
2 Voltage-divider
3 Current-transformer
4 Voltage-transformer
5 Lightning arrester

Fig. 4 b. Testing system of interruption of an unloaded, and reactor-loaded, transformer.

base frame of the circuit-breaker. The pilot valve 3 then returns to its original position, allowing air to flow into the space 4a. The moving contact 6 is then no longer held by the main valve disc 4, but is moved by a spring to the closed position as shown in Fig. 2. At the same time, valve 13 changes position and air flows into the space 12 in the resistor device, whereupon the resistor contact 8 also takes up a closed position.

TEST SYSTEM

Acceptance tests were made on the circuit-breaker at Kilforsen on 16th August, 1959. When breaking a line under no-load, use was made of a separate testing system with the 437 km line to Enköping and, at the same time, of the 23 km line to Ramsele which was fed by two 95 MVA generators. In the second type of breaking listed, a 3×100 MVA transformer group at the Enköping station was connected to the line. On testing, the transformer was either under no-load or was loaded on the tertiary side with a reactor output of 60 or 100 MVA. Tests on the breaking of a small inductive load were made with the supply taken from the grid via Ramsele. The interrupted transformer at Kilforsen had an output of 3×115 MVA and was, during the test, under no-load or loaded on the generator-voltage side with a reactor output of 40 or 80 MVA. The lay-out of the various testing systems can be seen from Figs. 4a and 4b.

When breaking lines, whether under no-load or loaded, the ordinary 400 kV lightning arresters were replaced by rod-type spark gaps in series with resistance mats rated at 200 ohms. It was assumed that the lightning arresters could be damaged by the discharges which might arise in the event of a restrike. The rod-type spark gap was set for a restriking voltage of about 1,150 kV, which, even with an error of 15 per cent, was regarded as providing adequate protection for the installation. The object of the resistance mat was to reduce the steepness of the wave front in the event of a flashover. Otherwise, the transformer insulation would have been exposed to, amongst other things, dangerous stresses when ignition occurred in the spark gap. The lightning arresters on the generator-voltage side were connected up during all testing. When breaking small inductive loads, the 400 kV lightning arresters were also connected up, while the rod-type spark gap was then removed.

When testing the reduced circuit-breaker, the capacitor voltage-transformers in the line to Ramsele were disconnected in order to reduce the risk of severe voltage stresses on the transformer insulation in the event of a restrike.

In order to reduce the risks in the event of an unsuccesful breaking operation, use was made of a back-up circuit-breaker in series with the test circuit-breaker when breaking lines both under no-load and under load. When breaking a small load, the test circuit-breaker was rapidly closed after each breaking in order to reduce the risk of the development of earth faults or short circuits in the event of an unsuccessful attempt at breaking.

MEASURING EQUIPMENT

For the field tests, use was made of one of the Swedish State Power Board's measuring buses, one of which is fitted with a ten-ray cathode ray oscillograph, an electro-magnetic oscillograph with 12 elements, a sequence controller, a photographic darkroom and a test control room. With the aid of this equipment, the phase voltages on both sides of the test circuit-breaker, the phase current and the tripping impulse were registered during testing.

Combined resistive and capacitive voltage-dividers connected between the phases and earth on each side of the test circuit-breaker were used to measure the voltage. These voltage-dividers consisted of a high-voltage section suspended in the phase line and a low-voltage section placed alongside the measuring equipment and connected to the high-voltage section by means of a coaxial cable. The low-voltage section has been improved, as compared with previous field tests, in so far as a damping resistor has been inserted, thus ensuring that the frequency characteristic is virtually linear up to about 70 kc/s.

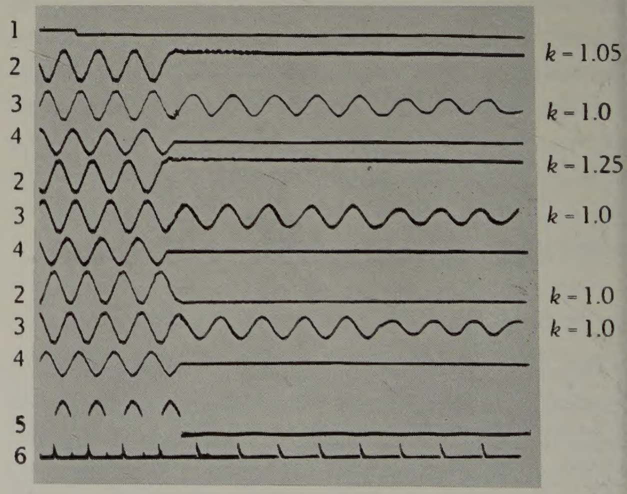
The currents were measured with the aid of ordinary current-transformers.

Before each test, the current and voltage were measured by means of ordinary indicating instruments and in order to obtain rapid indication of the results of each test, a directly recording oscillograph was used.

TEST RESULTS

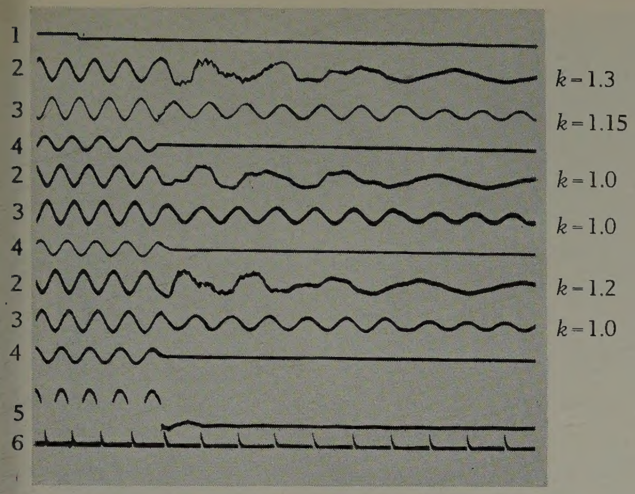
The results of the test can be seen in detail from Tables 1, 2 and 3. No restrikes occurred when breaking the line under no-load, not even when the circuit-breaker was without protective resistors and was reduced by two breaking elements. For this reason, the over-voltages occurring were very small, Table 1. Fig. 5 shows an oscillogram taken with the electro-magnetic oscillograph during these tests, the voltage before breaking being 539 kV. Further, when breaking the same line loaded with transformers either under no-load or loaded with reactors in the Enköping station, no restrikes occurred, and consequently, in this case too, the over-voltages were very small, Table 2. In a breaking operation of this kind, after breaking, an oscillation arises in the disconnected circuit with a frequency determined by the line capacitance and the inductance of the load. During the tests, this frequency was 17, 24 and 34 c/s in the case of reactor loadings of 0, 60 and 120 MVA. Thus, conditions are similar, to some extent, to those which occur on breaking during phase opposition, and relatively high voltages arise over the circuit-breaker, thus exposing the protecting resistor to severe thermal loading. An electro-magnetic oscillogram taken during these tests is shown in Fig. 6. The highest over-voltages occurred when breaking small inductive currents, Table 3. However, because of the effective damping provided by the protective resistor, the over-voltages were moderate in this type of breaking too. They reached their highest value on the breaking of a transformer loaded with a 40 MVA reactor, the over-voltage factor obtained then being 2.2. An electro-magnetic oscillogram of these tests is shown in Fig. 7.

During the tests, 55 in all, the total breaking time, that is to say, the total of the opening time and the arcing time was, on the average, 59 ms.



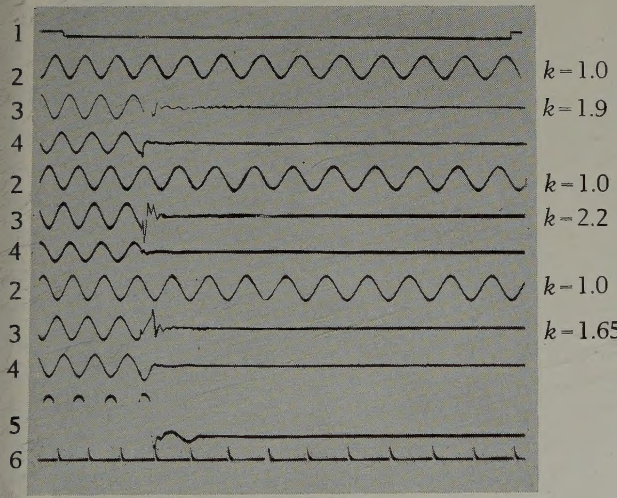
1 Tripping impulse
2 Phase voltage on the line side
3 Phase voltage on the station side
4 Phase current
5 Current through the resistor after the main interruption
6 Time indication

Fig. 5. Oscillogram of the interruption of an unloaded line with a reduced circuit-breaker. (Z 11524)



1 Tripping impulse
2 Phase voltage on the line side
3 Phase voltage on the station side
4 Phase current
5 Current through the resistor after the main interruption
6 Time indication

Fig. 6. Oscillogram of the interruption of a line loaded with an unloaded transformer. (Z 11525)



1 Tripping impulse
2 Phase voltage on the line side
3 Phase voltage on the transformer side
4 Phase current
5 Current through the resistor after the main interruption
6 Time indication

Fig. 7. Oscillogram of the interruption of a transformer loaded with a 40 MVA reactor. (Z 11526)

Table 1. Breaking of lines under no-load, 437 km (270 miles) and 23 km (15 miles). The neutral point of the system is directly earthed.

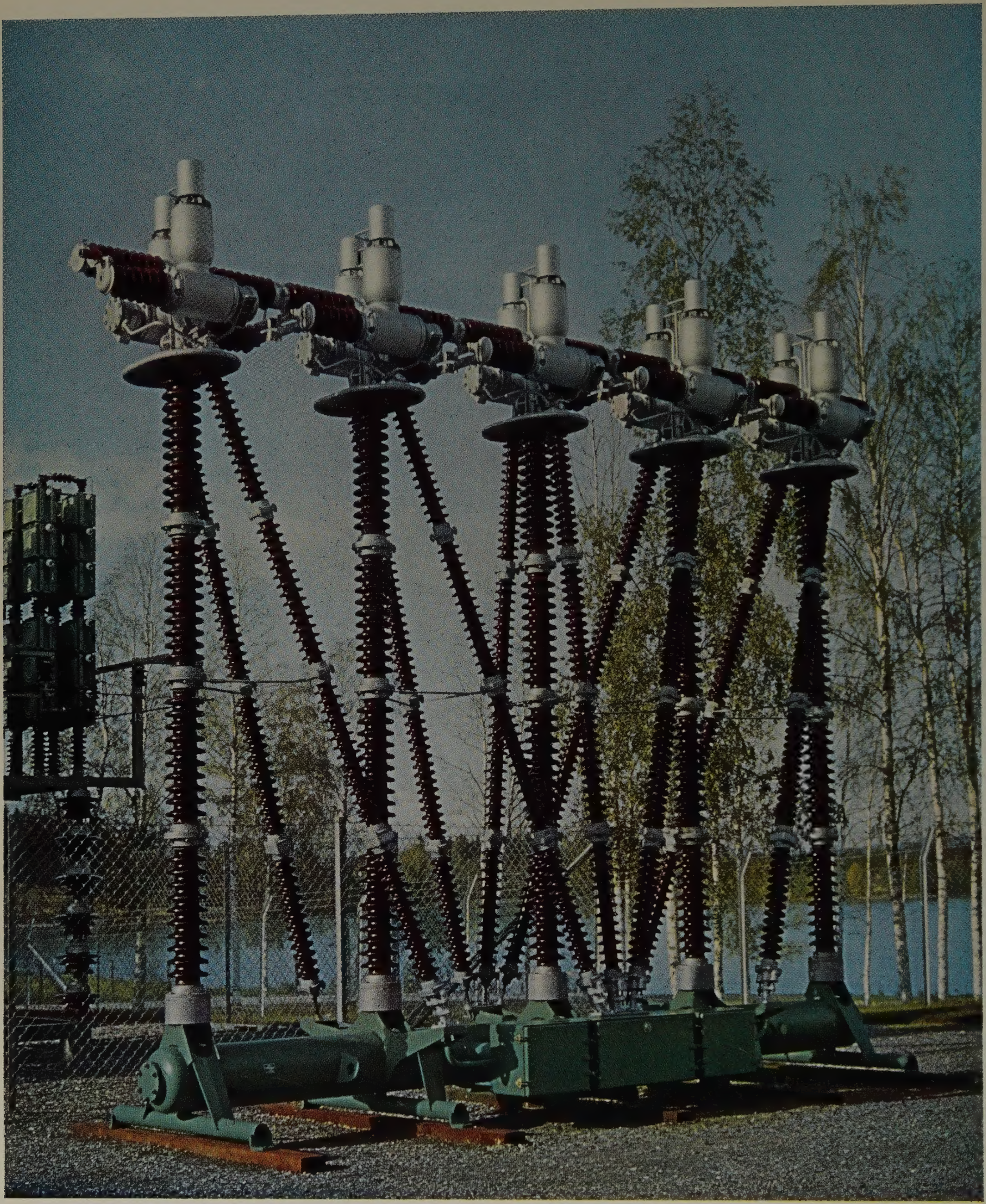
	Voltage before breaking, kV	Breaking current, A	Number of tests	Over-voltage factor				Maximum breaking time, ms
				Station side		Line side		
				Max. value	Mean value	Max. value	Mean value	
Complete circuit-breaker	326	338	1	1.10	1.07	1.30	1.10	61
	400	408	8	1.25	1.07	1.25	1.11	61
	476	484	1	1.10	1.04	1.25	1.11	58
	541	542	2	1.20	1.07	1.25	1.09	59
Reduced circuit-breaker	327	340	1	1.20	1.08	1.10	1.05	59
	400	408	9	1.20	1.04	1.30	1.10	60
	473	480	1	1.10	1.03	1.20	1.11	60
	539	544	2	1.10	1.02	1.25	1.10	58

Table 2. Breaking of a 437 km (270 mile) line loaded with a transformer and reactors at the further end (each reactor rated at 60 MVA). The neutral point of the system is directly earthed.

Load at the line end	Voltage before breaking, kV	Breaking current, A	Number of tests	Over-voltage factor				Maximum breaking time, ms
				Station side		Line side		
				Max. value	Mean value	Max. value	Mean value	
Transformer alone	400	400	3	1.20	1.08	1.35	1.21	60
Transformer plus one reactor	400	296	3	1.20	1.10	1.20	1.08	61
Transformer plus two reactors	400	209	3	1.30	1.15	1.25	1.08	58

Table 3. Breaking of inductive load, transformer under no-load or transformer loaded with reactors (each reactor rated at 40 MVA).

Inductive load	Voltage before breaking, kV	Breaking current, A	Number of tests	Over-voltage factor				Maximum breaking time, ms
				Line side		Transformer side		
				Max. value	Mean value	Max. value	Mean value	
Transformer alone	397	6.9	5	1.00	1.00	1.20	1.01	52
Transformer plus one reactor	394	61	7	1.00	1.00	2.20	1.53	59
Transformer plus two reactors	390	117	7	1.05	1.00	1.40	1.14	60



One pole of an air-blast circuit-breaker type HVH 420/1610 rated at 420 kV, 1,600 A, 15,000 MVA. (F 538)

THE CONTROL EQUIPMENT IN STORNORRFORS POWER-STATION

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The control equipment in Stornorrfors power-station is, on the whole, set up in accordance with the practice for the power-stations of the Swedish State Power Board. However, certain minor modifications have been made, for example, in the connecting up of the spare transformer, relay protection and turbine governing and these subjects are dealt with in some detail in the article. An account is also given of the scope and arrangement of the control equipment.

A general review of, and a circuit diagram for, Stornorrfors power-station is given in Asea Journal 33 (1960):1–2, pp. 3–8. This article on the control equipment is written in conjunction with the above-mentioned account and the same designations are used for the various components in the installation. [The circuit diagram is also printed in Asea Journal 33(1960):10–11, p. 161.]

The control equipment in Stornorrfors power-station has been set up in accordance with the practice developed over the years for the power-stations of the Swedish State Power Board. Naturally, minor modifications have been made from station to station as experience increased. In addition, at Stornorrfors, certain special arrangements at the station itself gave rise to special solutions as far as the control equipment was concerned. This applies first and foremost to the interlocking arrangements for the isolators as well as the tripping sequence for the 18 kV circuit-breakers which had to be arranged because no three-pole breaker with a breaking capacity equal to the total short-circuit power was available.

The characteristic features of the station will be dealt with in greater detail, while the rest of the control equipment will be described along broad lines only.

THE CONTROL EQUIPMENT

The greater part of the control equipment is built into panels and cubicles in the normal way and these are set up in the station at the most suitable points seen from the view of erection and operation.

The main control board is set up in the control room. It consists of 22 panels on the front of which indicating and recording instruments for the generator sets, the main transformers and the lines, as well as for measuring the water level and the position of the spillway gates are mounted at the front of the panel. The board also contains certain relay equipment, that is, operating relays for the synchronising equipment as well as temperature relays for supervising the temperature of the generator sets and the transformers.

The control desk is set up in front of the control board. Those panels which face each other on the control desk and the control board are for the same object in the installation. At the front and on the upper part of the desk there is the equipment for operating and indicating the main components of the installation. It is thus possible from this point to start and stop the generator sets, regulate the voltage and power, set the service damping of the turbine governing, lower the intake gates, operate the carbon dioxide batteries for the generators, and operate and obtain indications for all the circuit-breakers and isolators for the 18 kV, 40 kV and 400 kV switchgear.

The writing desk is in the centre of the control room. The staff on duty can sit at their places and supervise both the control desk and the control board. The telephone exchange of the station is built on to the writing desk. There is also a recording instrument showing the total generator output of the station and an instrument for measuring the upper water level.

To the right of the telephone exchange there is a slanting instrument panel with switches for temperature meas-

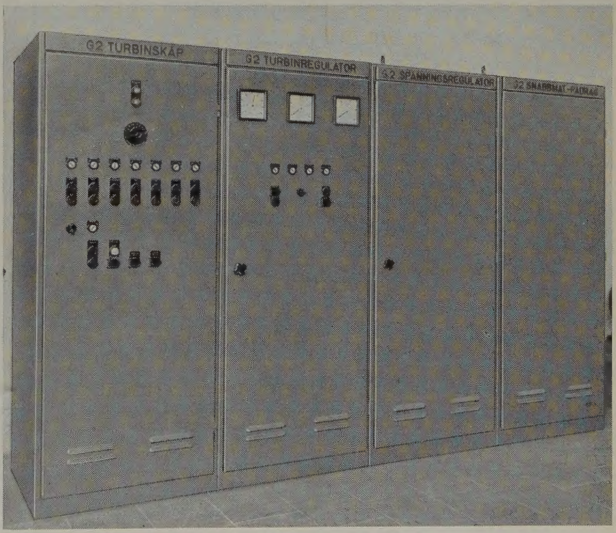


Fig. 1. Generator control board with four panels set up in the machine hall close to the set. (53879)

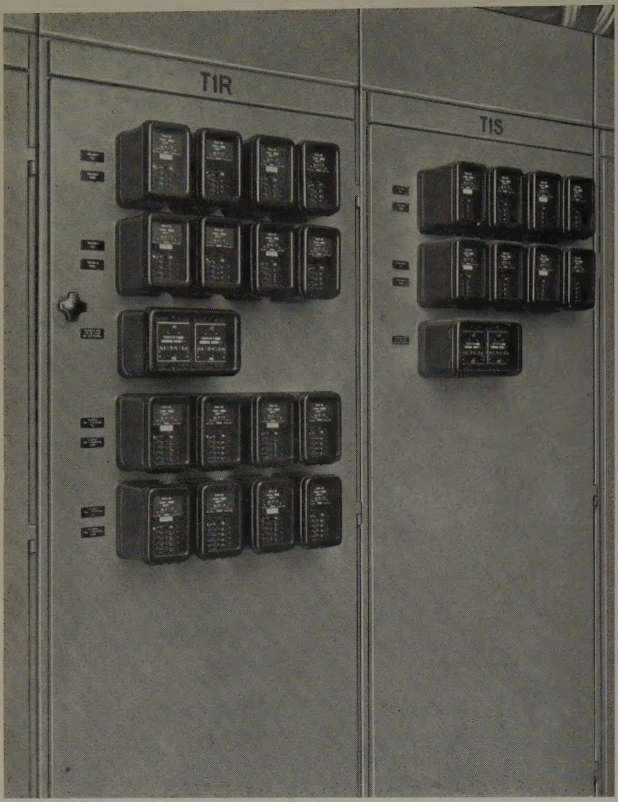


Fig. 2. Connection cubicles for the transformer units T1R and T1S. The cubicles are set up in the space beneath the control room and provided with mirror relays (type RMA 16) for isolators and circuit-breakers, as well as throw-over relays (type RRMVB 4) for switching over to the spare unit. (53886)

urement and, to the left, there is the setting gear for the turbine governor for the total power of the station, its frequency and regulating capacity. In addition, there is a loudspeaker and switches for the telecommunication links between the control room and other parts of the station. Switches for the alarm apparatus in the station are also located in this panel.

Behind the writing desk, against the wall, there is a combined board for the local power, signals and the transformer group T1.

All the protective equipment is grouped together in the relay room. The protective relays are mounted in panels each referring to a certain component of the installation. Circuit-breaker panels have been set up in conjunction with the protective relay panels. They also contain, amongst other things, the equipment for the 18 kV circuit-breakers described under the heading "Protective relay equipment".

In all, the protective relay equipment comprises 47 panels, which are divided up over 6 boards. However, this also includes spares for the future extension of the station, in the first place, for the planned 130 kV lines.

In the relay room there are also instrument panels for debiting and statistical measuring, distribution boards for the d.c. supply to the control equipment, and a panel for signal equipment.

In the machine hall a board with four panels is set up in conjunction with each generator set. Each contains automatic relay equipment for starting and stopping a turbine governor, a voltage regulator and a starter for the impulse exciter set (Fig. 1), in other words, equipment for the generator set alone. The main reason for placing the panels in the neighbourhood of the generator sets is that manual starting of the sets is carried out from these panels.

On the same floor there are also impulse exciter, and auxiliary impulse exciter, sets, shunt, and series, resistors for the field circuit of the exciter (Fig. 12) and the field circuit-breaker cabinet (Fig. 11). Because of its size, the discharging resistor, which is usually mounted in the field circuit-breaker cabinet has, in this case, been placed in a separate cabinet.

The cables between the power-station and control room etc. on the one hand and the intake house, outdoor switchgear, etc. on the other hand terminate in connection boxes or connection cabinets. In the control house, the connection cabinets are set up in the middle under the control room. Multi-contact mirror relays have been mounted on the doors of the connection cabinets. Their object is to reproduce the position of the indicating contacts on the isolators or circuit-breakers to which the relays are connected. Fig. 2 shows two connection cabinets with mirror relays for the 18 kV circuit-breakers and isolators for transformers T1R and T1S.

OPERATION AND INDICATION

All operation and indication of the components of the main system normally takes place at the control desk. The two-pole circuit-breakers for T1 can, in addition, be individually operated from the transformer control board. Further, the generator sets can be started and stopped from the boards in the machine hall. The control equipment for the local power installation is operated and indicated on the local control board only.

The turbine-generator set

Before the set can be started, a number of preparations have to be made. Thus, the oil-pressure pump must be working and the oil pressure must reach the normal value, the brakes must be off and the guide-vane lock must be in the locked position. Further, certain protective devices, such as the mechanical run-away protection and the temperature relays, must be reset if tripping has previously taken place.

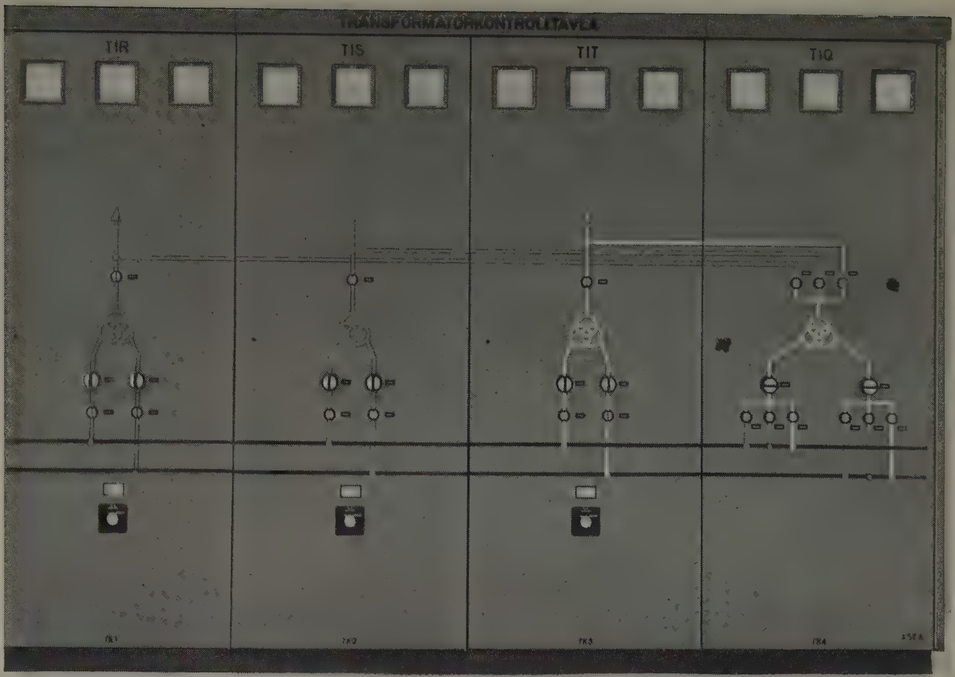


Fig. 3. Transformer control board for the main transformer. Beneath the mimic diagram on the panels for the ordinary transformers there are switches for connecting up the spare transformer. (54510)

If the requirements set out above are not fulfilled, starting is automatically blocked and the reason for the blocking is indicated on the turbine control board.

As has been mentioned above, the set can either be started from the turbine control panel or from the control desk. In the latter case starting takes place partly automatically, that is to say, certain auxiliary equipment is operated simultaneously. When starting from the turbine control board, this is operated manually by means of the operating devices on the board. It is thus possible to start and stop two oil-pressure pumps for the pressure tank of the set, the leakage-water pumps on the turbine cover and the leakage oil pumps for the leakage oil trough of the servo-motors. A d.c. oil-pressure pump for all the sets can also be started and stopped from the board.

In the case of single-button starting, the starting impulse is stored in the turbine automatic devices and brings about the starting of the two oil-pressure pumps, the opening of the valve for the cooling water to the bearing-oil coolers and the generator air-coolers, and the energising of the starting solenoid for the turbine.

When the set has reached 90 per cent of its rated speed, the starting relay is released, whereupon the one oil-pressure pump is stopped, since the consumption of pressurised oil at this stage of starting is relatively small. However, the pump starts up again automatically if the oil pressure drops.

From both the control desk and the turbine control board it is possible to switch off the set by means of the emergency stopping button, thus energising the stopping solenoid and opening the generator circuit-breaker and field circuit-breaker simultaneously. Emergency stopping can also be combined with the discharging of the carbon dioxide batteries for extinguishing fires in the generator chamber.

Isolators and circuit-breakers

All the isolators in the main system are provided with motor-operating gear and interlocking coils and can be operated either from the control desk in the control room or by means of built-in pushbuttons on the operating gear. The isolators can only be operated provided that the appropriate circuit-breaker is open. Interlocking is arranged with the aid of auxiliary contacts from the circuit-breaker, which interrupt the current for both the operating gear and the interlocking coil on the isolator, when the circuit-breaker is closed.

The design of the operating circuits for the isolators and circuit-breakers for the main transformer T1 presented particular problems because of the fact that the transformer comprises four single-phase units, that is, three ordinary ones in a three-phase bank and the fourth as a standby. This latter unit has to be able to replace any of the three ordinary units in the case of a fault on anyone of these, and reconnection is carried out by means of single-pole connecting isolators on the 400 kV side and two-pole ones on the 18 kV side; changing over takes place when the transformer is dead. However, normally, switching of the three transformer poles is carried out simultaneously, as would be the case with a normal three-phase transformer. Those transformers which are to be connected up are selected

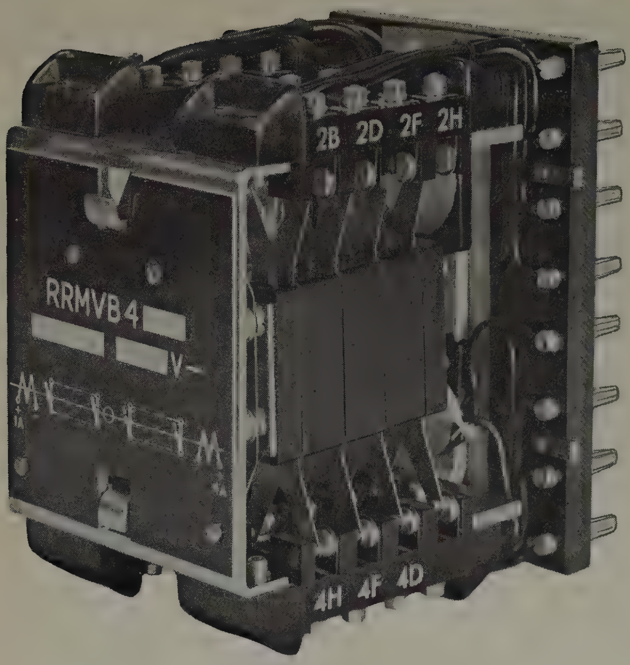


Fig. 4. Throw-over relay type RRMVB 4. (50101)

by means of an individual change-over switch for each ordinary single-phase transformer.

The change-over switches – one for each ordinary pole – are mounted on the transformer control board and have two positions, one for T1 and one for TQ (Fig. 3). Thus, the operating impulse is either sent to the ordinary transformer if the change-over switch is in the first position, or to the standby transformer if it is in the other position.

The three switches have a common operating handle which can be removed from a switch only when it is in the T1 position. This ensures that only one ordinary pole at a time can be replaced by the connecting up of the standby pole. Further, the switches are provided with interlocking coils and connection is so arranged that the change-over switches are released for operation only when all the isolators for T1 are open. The selector and interlocking connection described has made possible entirely satisfactory three-pole operation of the isolators from the control desk.

Since the isolators can be operated individually, in order to avoid material damage and injury to personnel, the isolators for the various windings on the standby transformer are mutually interlocked. In addition, on the 400 kV side there is interlocking between like isolators for the ordinary units and the standby unit, that is to say, the 400 kV isolator of the R-pole is interlocked with the 400 kV isolator of the Q-pole for the R-phase and vice versa.

Finally, the operation of individual 18 kV circuit-breakers, which can be carried out from the transformer control board, blocks when the appropriate isolator is closed. This means that the 18 kV circuit-breakers can be operated from the transformer control board only from that transformer which is not in service.

In the installations previously made, change-over switches of drum type have been used although they were somewhat bulky because of the large number of contacts required. At Stornorrfors, the change-over switch is provided with only a few contacts which are later reproduced with the aid of 14-pole throw-over relays, which are operated by means of the change-over switches. The throw-over relays are of two-position type with permanent magnets for keeping the relay in the one position or the other. Their external appearance can be seen from Fig. 4.

These throw-over relays, which have previously been described in Asea Journal 32(1959):6, p. 88, have made possible, amongst other things, a considerable simplification in the wiring since it has been possible to locate them in the installation at those places where the change-over function was required. Fig. 5 shows the relays in a protective relay panel for the transformer T1Q.

Indication as to whether an isolator or a circuit-breaker which consists of three separate poles is closed or open is not obtained until all the three poles have closed or opened. If any pole does not accompany the others or if any isolator should stop in the intermediate position, indication of this is provided too.

The tap-changers for T2 and T3

A few remarks are made below on the operation of the tap-changers for the 40 kV transformers T2 and T3. Each transformer is fitted with automatic devices which allow of five different types of service, that is:

Fig. 5. Protective relay panel for the transformer unit T1Q. The door carries the protective relays and in the cubicle the intermediate current-transformers have been mounted on the end wall and throw-cver relays for switching, on a separate sheet-steel plate (to the left in the cubicle). (53876)

1. *Parallel service* with the other transformer, which is then the leading one
2. *Hand operation* of the tap-changer by means of an operating switch on the control desk
3. *Automatic voltage regulation* in the normal way with a voltage relay
4. *Programme regulation,* in which a time switch connects up and disconnects the series resistor of the regulating relay, regulation then taking place at various voltage levels in accordance with a previously set programme
5. *Off-peak service* in which the voltage is regulated at a reduced voltage level

TURBINE PROTECTION

The turbine has been provided with the following protective equipment:

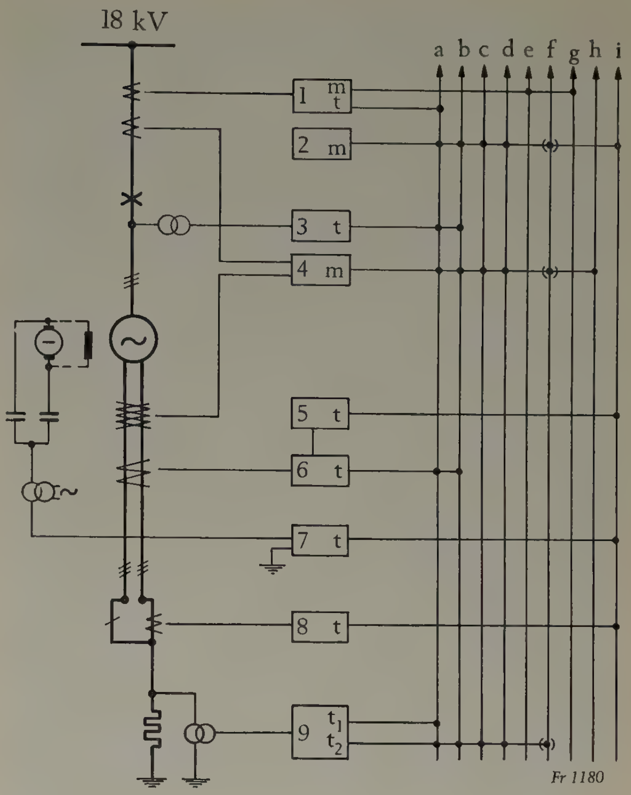
Three *overspeed devices* for protection against run-away. The first stage consists of an over-voltage relay, which is connected to the pendulum generator and, when it operates, drops out and stops the set as well as closing the intake gate. As a standby for this electric run-away protection, and set at a rather higher operating value, there is a mechanical run-away protection, which actuates the same tripping relay as the electrical protection, by means of a contact. Finally, as a last resort, there is a mechanical protection which stops the set hydraulically.

Four *oil-pressure relays,* that is, one which stops the oil-pressure pumps when there is overpressure and three which, when the pressure drops, carry out the following operations in the following order:

1. Connect up the no-load damping for the turbine governor at the same time giving a signal in the control room
2. Trip and stop the set
3. Lower the intake gate

Linkage-break relays, which, in the event of a break in the operating linkages for the turbine guide vanes, lower the intake gate as soon as the set is stopped. Thus, the relays do not put the set out of operation but only give a signal in the control room. Further, mechanical breaking is prevented until the intake gate has shut off the supply of water to the turbine. A further reason for applying the brakes is that the speed has dropped to a value less than about 40 per cent of the rated value. For this purpose, an under-voltage relay is connected to the pendulum generator.

The braking relay, which stops the set and trips the field and generator circuit-breakers if, for any reason, the brakes should move into the braking position during running.



1 Instantaneous over-current protection with high current setting
2 Flame-actuated relays
3 Voltage-rise protection
4 Differential protection
5 Thermal overload protection
6 Over-current protection
7 Earth-fault protection for the excitation circuit
8 Divided-conductor protection
9 Two-stage earth-fault protection for the stator windings
t Time-lag protection
m Instantaneous protection
a Tripping for generator circuit-breaker
b De-excitation
c Release of CO_2 battery
d Guide-vane closing
e Tripping of the 18 kV main transformer circuit-breakers
f Mechanical braking (takes place as a consequence of closing the guide vanes)
g Blocking of the generator circuit-breaker tripping
h Blocking of the 18 kV over-current protection for the transformers (rapid step)
i Signal

Fig. 6. The relay protection for the generators.

PROTECTIVE RELAY EQUIPMENT

As far as the generators and main transformers are concerned, the circuit diagram for Stornorrfors corresponds, in the main, with that for Harsprånget. This latter station has previously been described in, for example, Asea Journal 26(1953):9–10, pp. 130–137. It was therefore possible to design the principal features of the relay protection in a similar way, in spite of the fact that the rated output of the generators and transformers at Stornorrfors is considerably higher. However, it was possible to carry through a certain simplification of the relay circuits for the main transformer at Stornorrfors, in that

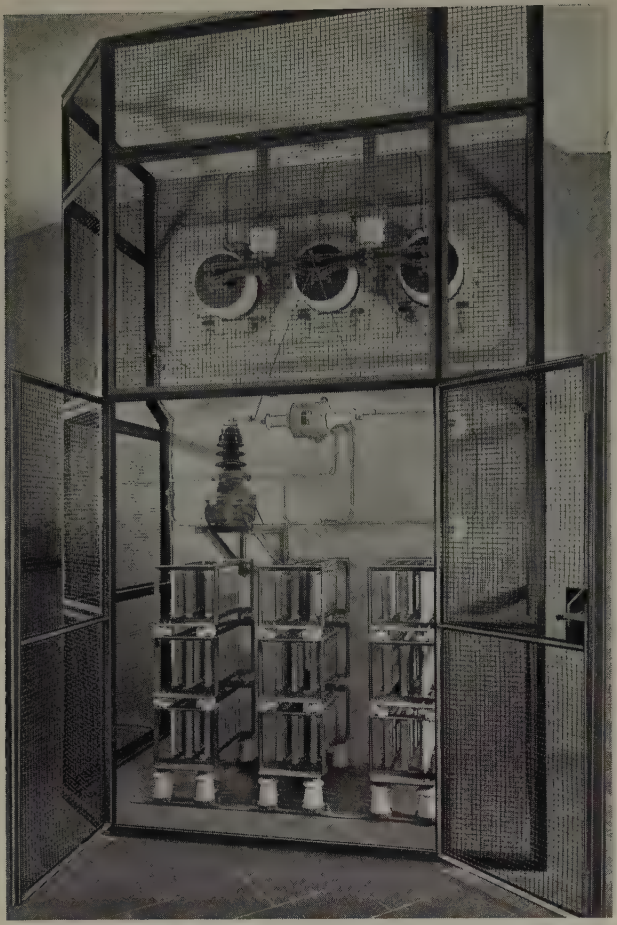


Fig. 7. Neutral-point equipment for a generator with, from the bottom: neutral-point resistor, voltage-transformer, current-transformer for divided-conductor protection and three current-transformers in the generator cylinder. (53891)

the fourth single-phase transformer – the standby transformer – when being substituted is connected up to the system when it is dead, which is not the case at Harsprånget Power-station.

Naturally, the greatest importance has been laid on the rapid and selective disconnection of short circuits on the individual components of the installation, bearing in mind partly the stability of the network in the case of disturbances, and partly because of the exceptionally high short-circuit powers which can occur in this part of the grid. However, there are certain limitations to the stability of tripping the generators and the 18/40 kV transformers selectively in the case of heavy short-circuit currents, since the 18 kV circuit-breakers for these components of the installation are not designed for breaking heavier short-circuit powers than 2,000 MVA. Therefore, a protective circuit has had to be used. If the short-circuit power exceeds the breaking capacity of these circuit-breakers, the 18 kV circuit-breaker of the single-phase transformer is tripped instead.

In the case of the station protection, it has been possible to use Asea's normal standard relays throughout, and relays of plug-in type inserted in relay cases have been used to a very great extent.

A broad account is given below of the relay protection for the various individual objects protected.

Generators

As will be seen from the circuit diagram of the station, when the installation is complete, two generators will be connected to each 18 kV busbar. Each of these bars in its turn feeds one 18 kV winding of the three single-phase transformers. By means of this circuit, two separate 18 kV systems are obtained, in which one or two generators can be in service or disconnected independently of each other. Therefore, each circuit-breaker has been provided with relay protection which, when it functions, only trips the main circuit-breaker, field circuit-breaker etc. of the faulty machine, in accordance with the diagram in Fig. 6. The protective circuit described above constitutes an exception. In the case of heavy short-circuits close to, or in, the machine, the 18 kV circuit-breaker of the main transformers is tripped instantaneously by the over-current protection 1 in the diagram at the same time as the tripping of the generator circuit-breaker is blocked. This protective connection implies that two generators may cease to feed the 400 kV network in the case of a serious fault in only one machine.

Otherwise, the relay protection is of the same design as is normally used for large generators.

The protection against short circuits and double earth faults in the stator winding consists, in the first place, of an Asea generator differential protection of extremely sensitive and instantaneous type. This functions at a primary fault current of about 50 A, that is to say, less than 1 per cent of the primary rated current of 6,000 A of the current-transformers. In the case of heavy-circuit currents, the tripping time amounts to, at the most, 70 ms.

The earth-fault protection of the generator is designed as neutral-point voltage protection with two time steps. It operates at 5 per cent of the full neutral-point voltage and thus protects 95 per cent of the stator winding. An earth fault in one of the 18 kV systems gives rise, in the first step, to tripping only of the main circuit-breaker of the connected generators. If the fault is located in one generator, this machine is stopped by the second time step of the earth-fault protection, whereupon the second machine can rapidly be synchronised to the system again.

Each generator neutral is earthed via an air-cooled temperature-dependent neutral-point resistor for a maximum earth current of 10 A. It is located with the other neutral-point equipment in the immediate vicinity of the current-transformers on the neutral side, see Fig. 7.

In addition to the protective devices mentioned above, the generators are also provided with fire protection, over-voltage protection, divided-conductor protection for the stator windings, earth-fault signalling device in the field circuit and thermal overload protection. The three latter devices are connected for signalling only. In the case of short circuits on the 18 kV busbars, the generators connected to them are disconnected after a short time-lag by the over-current protection on the neutral side of the generators.

The main transformator group T1 for 18/400 kV and the 400 and 18 kV busbars

From the point of view of relay protection, each of the four single-phase transformers is regarded as a separate unit. Thus, each transformer and appropriate 400 kV cable is provided with the following protective equipment, the circuit being in principle as shown in Fig. 8.

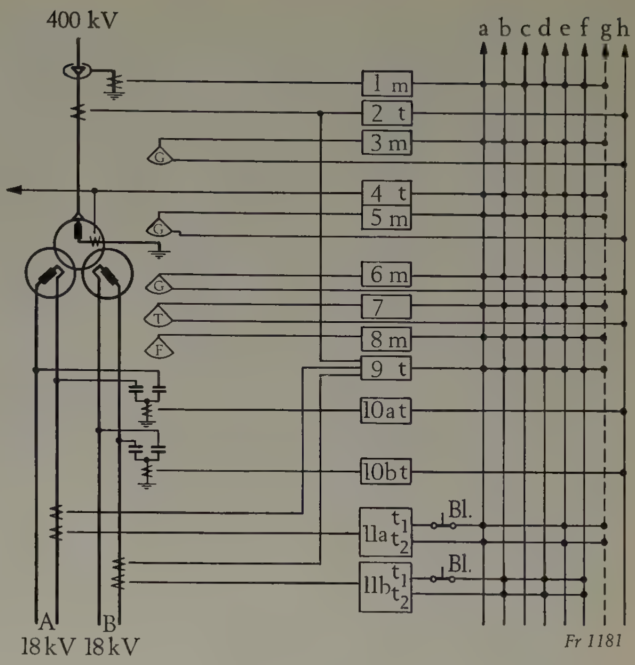
1. Three-point rapid differential protection connected to a current-transformer on each 18 kV side, and to a cable current-transformer mounted around the 400 kV cable
2. Gas-operated relay for the 400 kV box, the 400 kV bushing and transformer and temperature-operated relay and fire protection (flame-actuated relays)
3. Flashover protection connected to the arcing ring on the upper cable end box
4. Thermal overload protection on the 400 kV side
5. Earth-fault protection for each 18 kV winding

Transformer and cable faults which are of such a nature that tripping has to take place, disconnect both the main transformers and the generators.

In addition to the above-mentioned protection for the transformers, there is the following busbar and spare protection connected to current-transformers in the 400 kV neutral and on the 18 kV side:

1. Neutral-point current protection for 400 kV, common to all four single-phase transformers
2. Over-current protection for 18 kV, with one rapid step and one spare step

The main purpose of the over-current protection is to cause tripping in the event of short circuits on the 18 kV busbars. In order to prevent unnecessary disconnection of the main transformers in the case of a short circuit in the generators and transformers connected to the 18 kV busbar, or on the 400 kV and 40 kV lines, the selective short-circuit protection for these items has to give an instantaneous blocking impulse to a blocking relay common to all the 18 kV over-current protection equipment, which puts the rapid step out of action.



1	Flashover protection
2	Thermal overload protection
3	Gas-operated relay for the 400 kV connection box
4	Neutral-point current protection
5	Gas-operated relay for the 400 kV bushing
6	Gas-operated relay for the transformer
7	Temperature-operated relay
8	Flame-actuated relay
9	High-speed differential protection
10	Earth-fault protection for the 18 kV side of the transformer
11	Two-step over-current protection
t	Time-lag protection
m	Instantaneous protection
Bl.	Blocking from the differential protection for the transformers and generators, as well as distance protection for the 40 and 400 kV lines
a	Tripping of the 18 kV transformer circuit-breaker, A-system
b	Tripping of the 18 kV transformer circuit-breaker, B-system
c	Tripping of the 400 kV transformer circuit-breaker
d	Tripping of the generator circuit-breaker G1
e	Tripping of the generator circuit-breaker G2
f	Tripping of the generator circuit-breaker G3
g	Tripping of the generator circuit-breaker G4
h	Signal

Fig. 8. Relay protection for the main transformers.

Fig. 9 shows the relay protection for the single-phase transformers arranged and mounted on panels, one for each individual transformer T1R, T1S, T1T and T1Q.

In addition, each 18 kV busbar has neutral-point protection which, after a time-lag, trips the corresponding 18 kV circuit-breaker in the case of a persistent earth fault.

The 18/40 kV transformers and the 40 kV busbars

The three-phase transformers T2 and T3 are provided with rapid differential protection which is, in principle,

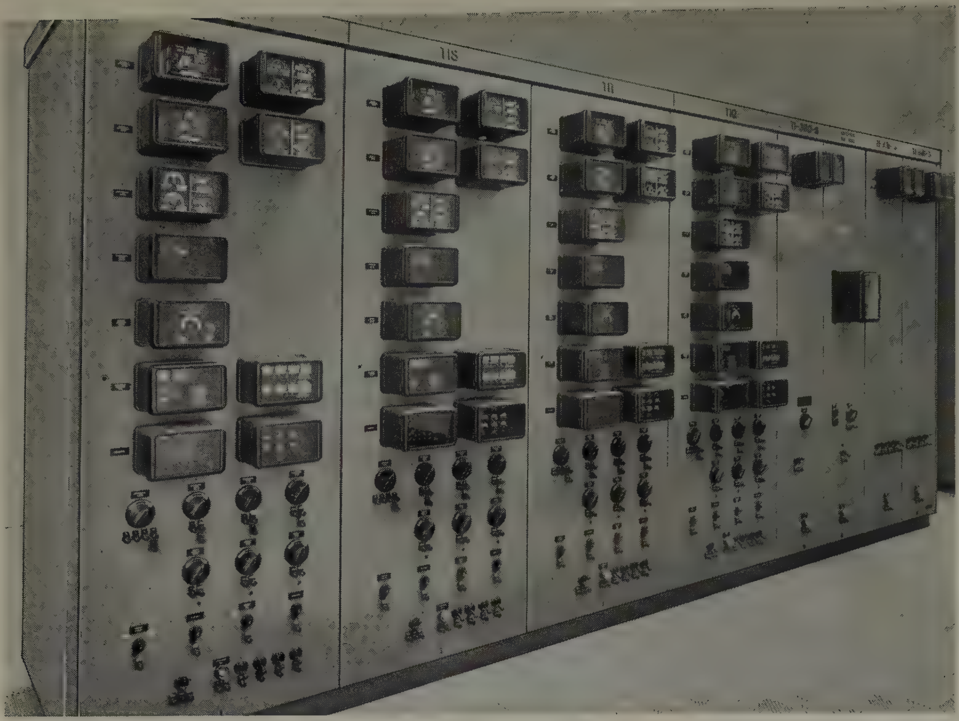


Fig. 9. Relay board for the main transformer which consists of three single-phase units and a spare unit. (53875)

of the same design as that for the main transformers described above, but, on this case, the protection is of three-phase type.

The over-current protection on the 18 kV side of the transformers is of three-step type. The first step consists of an instantaneous over-current protection device connected to trip the circuit-breakers of the main transformers.

This instantaneous protection fulfils the same object as the instantaneous over-current protection for the circuit-breakers when the short-circuit power exceeds the breaking capacity of the circuit-breakers for the transformers T2 and T3. The other two steps are, in principle, of the same design as the over-current protection on the 18 kV side of the main transformers and fulfil the same object, that is to say, rapid tripping in the case of a fault on the 18 kV busbars, but time-lag standby tripping in the case of short circuits in the transformers and generators.

In addition, the transformers are provided with differentially connected earth-current protection for the 40 kV side, earth-fault protection for the 18 kV winding which is similar in principle to that of the main transformers, and, finally, gas-operated relays and fire protection.

The 40 kV busbar is provided with a two-step neutral-point voltage protection device set for a longer operating period than the selective earth-fault protection of the 40 kV line. The first step disconnects the 40 kV lines on the local transformer LT8. The second step trips the 40 kV circuit-breaker for both T2 and T3.

The 400 kV and 40 kV lines

Both the 400 kV and 40 kV lines are provided with normal line protection, which, in the case of the 400 kV line consists of distance protection and three-step earth-current protection, and in the case of the 40 kV lines, of normal over-current protection and directional earth-current protection combined with rapid auto-reclosing.

Both the 400 kV and 40 kV systems are provided with over-voltage protection which trips the 18 kV transformer circuit-breakers after a short period. The object of this is to prevent dangerous voltage rises when the line is opened at the receiving end.

The local system

The local installation, which comprises two local transformers LT1 and LT2 for 18/0.4/11 kV and one transformer LT8 for 40/11 kV, are provided with the protective equipment which is normal for installations of this kind.

SYNCHRONISING EQUIPMENT

For manual synchronising there is a metering set with double voltmeter, double frequency-meter and synchroscope on the control board, and for automatic synchronising, a synchronising device of type TSTA.

Synchronising can be carried out with all the 18 kV circuit-breakers, the 400 kV circuit-breaker and the circuit-breakers for the 40 kV lines. The voltages for synchronising are taken from a capacitor voltage-transformer on the 400 kV line, capacitor-potential device on the current-transformers of the 40 kV lines and otherwise from normal magnetic voltage-transformers.

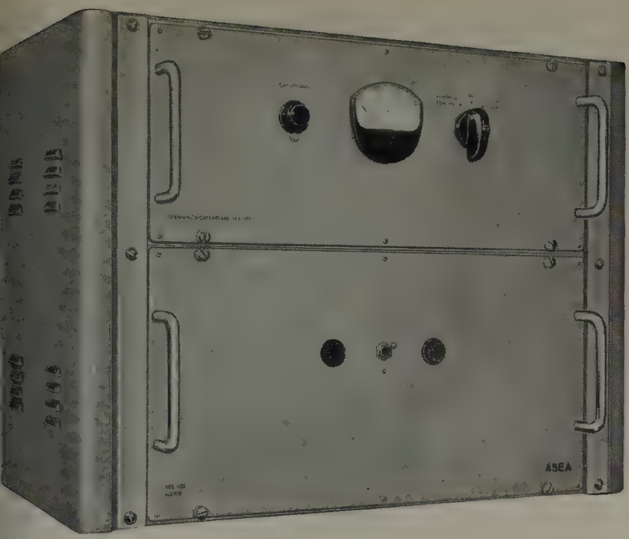


Fig. 10. Amplifier for connection to the capacitor-potential device on the current-transformers of the 40 kV lines. (53890)

However, the capacitor-potential device cannot be loaded with metering equipment and synchronising gear without the voltage dropping to an unpermissable value. For this reason, an amplifier (Fig. 10) is connected to the capacitor-potential device for the line which is to be connected up. Thus, the amplifier can be connected to the various lines in turn.

At Stornorrfors, the synchronising switches in use in earlier stations have not been adopted and, instead, operating relays have been installed for linking the reference voltages with the synchronising equipment. The relays are operated by means of the normal operating switches for the circuit-breakers by pulling out the knob. If the knob is kept pulled out for less than 2 seconds, only the synchronising metering set is connected up, otherwise, the automatic synchronising gear is also connected up.

After the operating switch has been released, the operating relay keeps itself closed with the aid of its own hold-in contact and is switched off by the circuit-breaker appropriate to the relay. This prevents any possibility of "pumping" and, for this reason, special protection against this has not been installed. If it is desired to cancel the phasing order, the relay can also be reset manually by pulling out the knob again. The relays are internally interlocked so that only one can be closed at a time.

SIGNALLING EQUIPMENT

The signal equipment is of two-lamp type, that is to say, it has a fault lamp and an acknowledgement lamp, and comprises in all 600 signalling points divided up over 10 signalling stations. However, this number includes 200 for future extension to the station.

On the writing desk, 16 group indicators have been arranged for the different parts of the installation, such as for the generator sets, the transformers, switchgear, etc. If a fault should occur within one of these parts of the installation, the fault itself is shown up on the signal board, but, in addition, the group signal lamp on the writing desk lights up for the part of the installation in question as long as the fault remains.

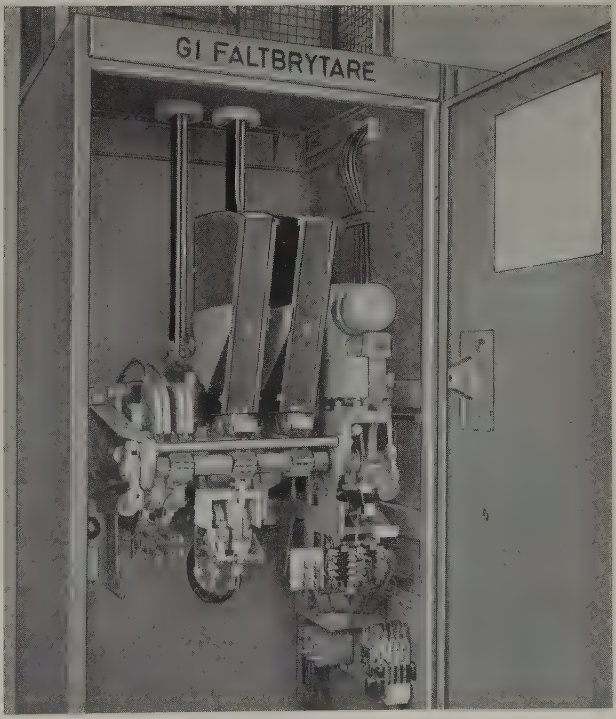
There is also a device in the signal equipment which will give a signal if anything should happen to the engineer on duty when the station is staffed by one man only. This man must report once an hour to a supervisory equipment, and he does this quite simply by pressing a button which is electrically connected to the equipment. If he does not do this, a signal is sent out to the homes of the staff off duty.

If the engineer has to leave the control room and is thus unable to carry out this hourly report, he can put this hourly supervision system out of action by means of a switch. Instead, a time relay is connected up which allows the engineer to remain away from the control room for a certain predetermined time. If the switch is not reset before the end of this period, a signal is sent out.

TEMPERATURE SUPERVISION

For supervision of the temperature in certain items in the installation there are built-in mercury thermometers (for bearings, transformer oil) and temperature-dependent resistor elements, which, via a change-over

Fig. 11. Field circuit-breaker for the field windings of the main generator and exciter. (53884)



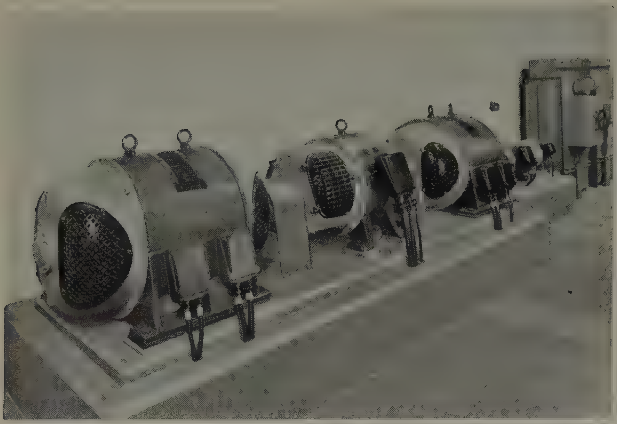


Fig. 12. Impulse-exciter set with the driving motor in the middle and two impulse-exciter machines. Behind the impulse-exciter set a glimpse can be seen of the auxiliary impulse-exciter set and, behind this, the rheostat and fixed resistor for the excitation. (53883)

switch, can be connected to a cross-coil instrument from which the temperature can be read off direct. The change-over switch and instrument are located on the sloping panel of the writing desk.

For each of the bearings of the generator set, the measuring equipment has been supplemented by two temperature relays of which the one gives a signal at a selected temperature. If this is exceeded, generally by 5°C, the other relay causes tripping and stops the set.

The generator winding has three resistor elements per phase which, via temperature relays, give a signal when the temperature becomes too high.

There are also resistor elements in the 18 kV windings of the single-phase transformers, on the sheathing and cable end boxes of the 400 kV cable, and in the two shafts for the 400 kV and 40 kV cables, the relays connected to all these elements giving a signal only.

An equipment for recording the temperature of the generator windings has also been installed.

INSTRUMENTS AND METERS

All the instruments have centrally pivoted pointers and a 240° scale and are 144 mm (5.7 in.) square. The instrument equipment for a generator set comprises ammeters for the stator current and rotor current, a voltmeter and meters for the active and reactive power, a voltmeter for the pendulum generator graduated in r/m, voltmeters for the voltage and turbine regulators, and voltmeters for indicating the position of the rheostat and guide vanes.

The main transformers have been provided with instruments for current, and active and reactive power.

The lines have instruments for current, voltage, active and reactive power.

On the transformer control board there are instruments for the current in the three windings of the single-phase transformers.

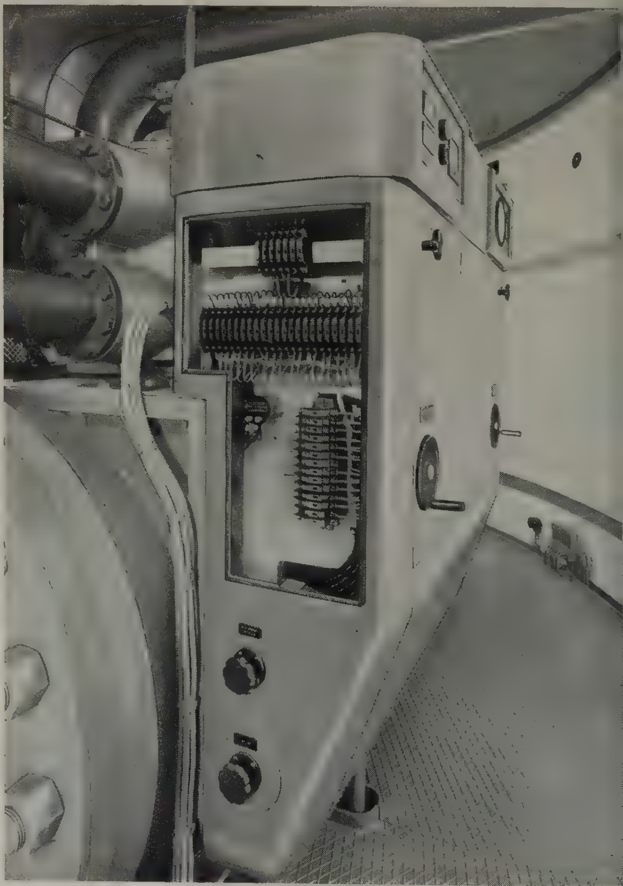
The board for local power has instruments for current, voltage and active power on the local transformers LT1 and LT2, for the frequency on the 10 kV busbar, for current and voltage on the batteries and charging converters.

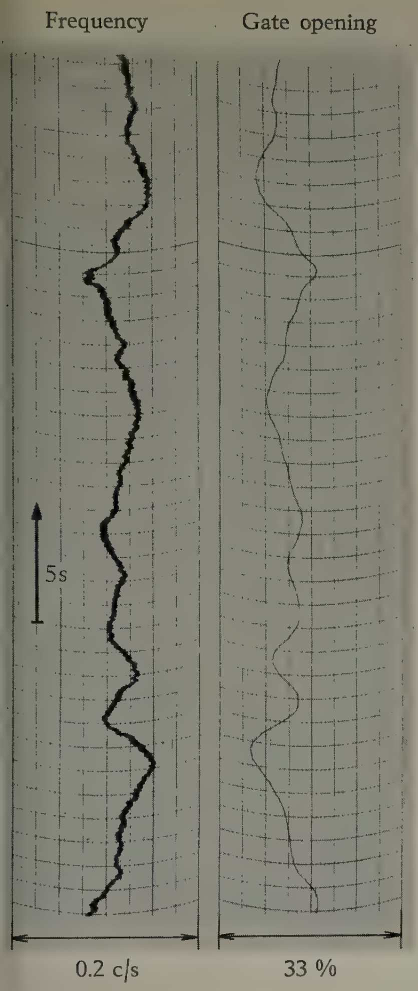
For measuring the position of the three spillway gates there are voltmeters on the control board graduated in metres of gate opening. Finally, there are instruments for showing the water level at the upper water surface, at the ward of the water surface downstream from the station, and in the shaft for the tailrace gates. The two first-mentioned measuring points are arranged for both coarse and fine measuring.

There are recording instruments for the combined generator output, the voltage on the 400 kV and 40 kV systems, the frequency, the winding temperature of the generators and the water level.

The equipment for measuring the energy consists of kWh-meters with impulse contact. The impulses are fed

Fig. 13. Electro-hydraulic actuator gear for turbine governing (placed on the main servo-motor for the turbine guide vanes). (53895)





Speed droop
1 per cent

Transient
speed droop
0 per cent

Fig. 14. Record chart intended to show the great sensitivity of the electro-hydraulic governor. This registration was taken when the governing equipment for Stornorrfors was tested in the Nohab testing room. (Z 10527)

into a counting panel with two sets of cunters, which are used alternately for an hour at a time. The readings obtained are used for statistical purposes.

For debiting purposes, the impulses are also transmitted to a counter via a summation meter.

FIRE EXTINGUISHING

For fire extinguishing, carbon dioxide equipment has been installed for the generators and combined water and foam extinguishing equipment for the transformers.

The CO_2 installation consists of two carbon dioxide batteries of equal size, which are each divided up into a section for rapid discharging and a section for slow discharging. With the aid of a switch, the one or the other battery can be selected for service while the other is then in reserve. The doors to the generator compartment are provided with contacts which prevent the operation of the CO_2 batteries if any door is open. Thus, when anyone is in the generator compartment, it is not permitted to have all the doors closed. If a fire should start or if the danger of fire should arise, personnel in the generator compartment are warned by means of alarm bells. After the staff have left the generator compartment and closed the doors the CO_2 batteries start to function. They are actuated by flame-operated relays which are mounted on the generator and from the tripping relays for the generator differential protection and the second time step of the neutral-point voltage protection.

When the fire-extinguishing equipment for the transformers starts to function, all the ventilating fans are stopped.

REGULATION EQUIPMENT FOR THE EXCITATION AND VOLTAGE

The equipment for excitation, and voltage, regulation is of the same type as has been supplied to the majority of large hydro-electric power-stations in Sweden during the last 15 years and has been described in detail in various numbers of this journal and in pamphlet No. 7350 E on the Harsprånget Power-station.

It need only be mentioned here that, because of the high excitation power required for the generator a new field circuit-breaker rated at 2,000 A had to be added to our previous series (Fig. 11).

The signals from the transductor regulator for voltage regulation are amplified in a two-stage machine amplifier. The first stage consists of an auxiliary impulse exciter and the second stage of an impulse exciter with a maximum power of about ± 45 kW at ± 670 V. The impulse exciters and auxiliary impulse exciters have their own d.c. driving motors (Fig. 12). The main exciter which is connected directly to the generator has a rated output of 575 kW at 365 V, and a maximum voltage of about 600 V.

TURBINE GOVERNORS

The electro-hydraulic turbine governors at Stornorrfors work in accordance with the basic principle described in Asea Journal 25(1952):4–5, pp. 44–56. However, in its practical design, the equipment varies somewhat from the present standard.

The actuating gear, which includes amongst other things the electro-hydraulic transducer used for conversion from electric to mechanical steering quantities, has, at Stornorrfors, been located in direct connection with the main distribution valve and the main servo-motor. This means that the mechanical connection between the actuating gear and the main distribution valve can be designed as a single link. It has thus been possible virtually to eliminate those properties such as play, friction and springing which would have a deleterious effect on the operation of the device. Since the main servo-motors, two per turbine, are located on the turbine cover immediately above the gate-operating ring the above-mentioned favourable conditions also apply to the mechanical restoring gear.

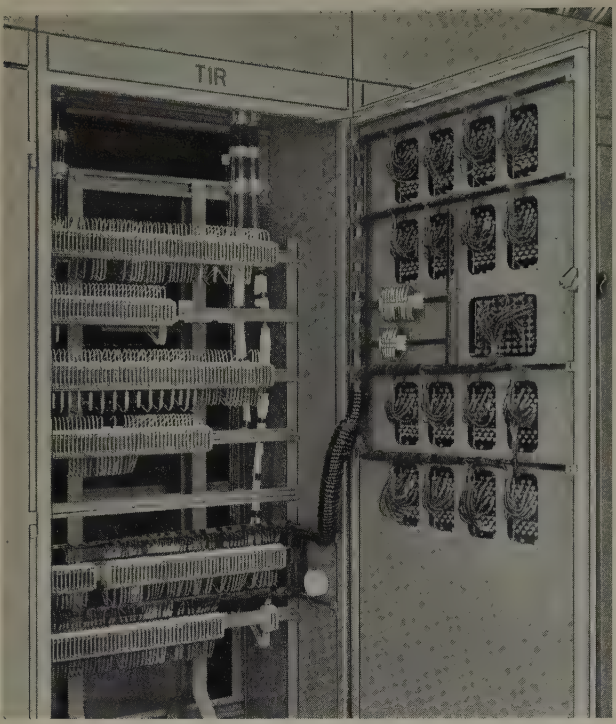


Fig. 15. The connection cabinet shown in Fig. 2, with the door open. The cables enter from above. At the extreme right, the multi-conductor cables can be seen and, to the left, the bundled control cables with fewer conductors. (53887)

The actuating gear is manufactured by Messrs. Nohab, Trollhättan. The electrical components were manufactured by Asea. Fig. 13 shows the actuating gear and its location on the main servo-motor. The electro-hydraulic transducer is placed under the cover and it operates the auxiliary servo-motor via a pilot valve. The feed-back required for stabilising regulation and for various other purposes is taken from this servo-motor by means of induction devices.

The regulator cubicle which is placed on the generator floor contains the turbine governor, protective and switching relays and various other auxiliary equipment. On the door of the cubicle there are the operating and indicating devices which are required for starting and stopping the turbine.

All the operating and setting devices for turbine regulation are located on the desk and the writing desk in the control room. The desk panel for the respective generators contains the individual items of control equipment which consist of setting devices for frequency and output and switches for changing over from one type of regulator service to another (manual – automatic, service damping – no-load damping, separate operation – joint operation). In the case of joint operation, which is the normal one, the setting of output and frequency is transferred to setting devices common to the station, located on the writing desk. There is also a third setting device for the regulating capacity (MW/c/s). The set values then give the station a certain given regulating characteristic which is independent of the number of generators running. Further, in the case of joint operation, a powerful continuously operating load distribution is obtained which sets the mutual output of the turbines so that optimum total efficiency is obtained.

The record chart in Fig. 14 which was taken for unit No. 1 at Stornorrfors shows the great sensitivity of the electro-hydraulic turbine governor. There is no insensitive range between frequency and the response of the gate opening.

ERECTION

For the control equipment installed exclusive use has been made of plastic-insulated cables with wire marking stamped on in the factory.

In the case of long reaches of cable, for example from the control room to the switchgear, the cables from the control boards and individual items of control equipment have first been grouped in a connection cabinet in which they have been connected up with multi-conductor cables (Fig. 15). These cables comprise the link to the corresponding connection cabinet in the switchgear from which cables are then run to the various items of switchgear equipment or their connection boxes.

The multi-conductor cables are of two types, that is, 91×1.5 mm^2 for operation, indication and signalling and 37×6 mm^2 for the connection of current and voltage transformers.

Each set of instrument transformers has been provided with a connection box which has been erected in the neighbourhood of the transformers and in which all the secondary terminals of the latter are connected to one or more terminal blocks. With this arrangement, it is possible to reconnect the instrument transformers during service as well as when they are dead. All earthing of the secondary circuit has been carried out in these connection boxes.

Inside the subterranean station, the cables have been placed on cable ladders or, where there are relatively few of them, on anchor bars by means of clamps.

Beneath the control room there is a special cable room in which the cables lie directly on the floor.

Outdoors in the switchyard, the cables have been placed in concrete channels which have been covered with wooden covers.

All the cables and cable cores have been provided with marking in accordance with Swedish Standard SEN R 36 03 11, that is to say, the cable number on the cable sheath and the connection number, core number and cable number on the individual cores.

AN ITALIAN WIRE-ROD MILL FOR HIGH-QUALITY STEEL

Tage Lundberg, Soc. Italiana di Elettricità Asea, Milan

U.D.C. 621.771.252:621-531.6
621.944.5
Asea Reg. 818

The wire-rod mill described in this article is at the Aosta works of Nazionale Cogne Società per Azioni, Turin, one of the oldest steel-producing firms in Italy. By far the greater part of the electrical equipment, including such specialist items as photo-electric loop regulators, was supplied by Asea or by Asea licensees in Italy.

The Nazionale Cogne steelworks is situated near the old iron-working town of Aosta, in the beautiful Aosta valley (Fig. 1). The company primarily manufactures products of high-grade carbon steel and high-alloy, and other special, steel. Work in the old wire-rod mill, which was taken into service in 1938, ceased at the end of 1960. The main reasons for this are that the profitability of the works has become unsatisfactory, since production capacity in relation to running costs, mainly the cost of labour, has become too low. Secondly, the equipment is not up-to-date and does not permit the meeting of modern requirements for close tolerances and the surface finish of the rolled wire. Thirdly, wire-drawing mills nowadays require heavier coils than those that could be produced in the mill hitherto.

The new rolling mill was taken into service in 1959 and was specially planned for the production of rods of quality steel for such purposes as wire ropes, ball-bearings, springs and tools. A simplified plan of the mill is shown in Fig. 3.

When planning the new mill, the following points were taken into consideration:

1. The billets produced by the company's own blooming mill have a square section of 4.8×4.8 inches (120 × × 120 mm) which means that the rolling mill has to make a total reduction 30 per cent greater than that regarded as normal for this type of rolling mill.
2. The highest demands were to be made on the tolerances and surface finish of the rolled rod.
3. The mill had to be built for a widely differentiated rolling programme, that is to say, it was to be possible to roll steels of the most varying qualities.
4. Because production would mainly be in short series, the mill had to be planned so that the change-over from one production programme to another could be carried out in the shortest possible time.

A description of the project has been published in Stahl und Eisen 78(1958):22, pp. 1611–1613 and in Metallurgia Italiana 49(1957):11, pp. 763–773. To fulfil the second condition mentioned above, stretching of the rod had to be avoided. This meant that loops would have to be formed between one stand and the next and that only one rod could be rolled at a time. Thus, in order

Fig. 1. The Nazionale Cogne rod-rolling mill near Aosta, Italy. (55165)

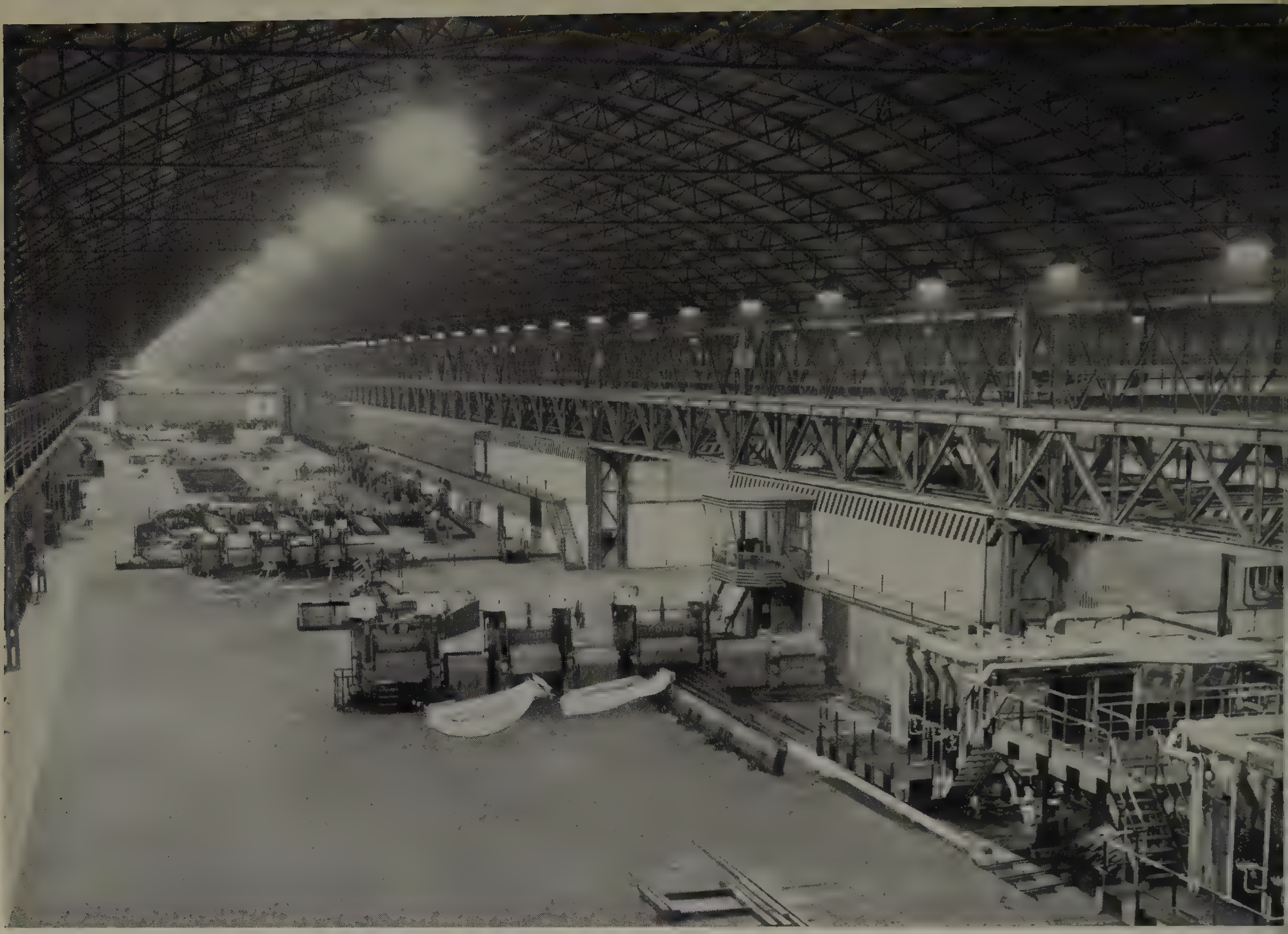


Fig. 2. General view of the rolling mill showing the roughing, intermediate, looping and continuous mills. (55162)

to achieve a satisfactory rate of production, heavy coils and high outgoing rod speeds would be required.

Particularly when rolling stainless steel, the cooling of the rod has to be avoided. This material can only be worked within a very small temperature range which means that the difference in temperature between the beginning and the end of the rod must be strictly limited. To reduce cooling, the loops must be short, and this applies especially to the loops in the rod mill since, because of its small diameter, the rod cools very rapidly.

The demand for short change-over times when switching from one programme to another necessitates relatively advanced automatic control, primarily of the motor speeds.

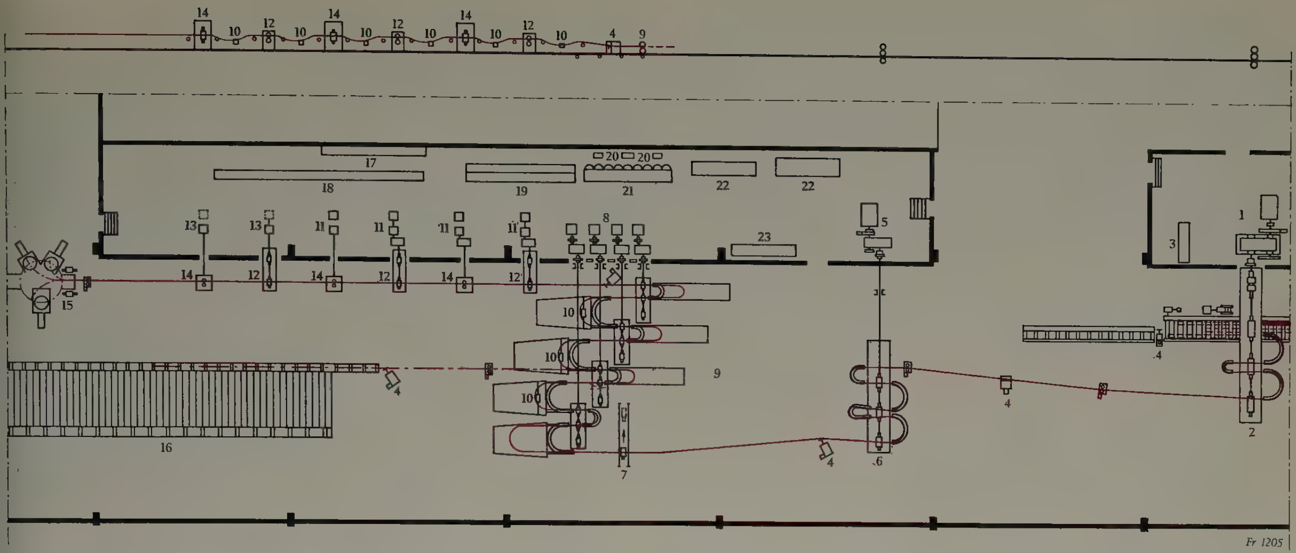
Messrs. Luigi Pomini, Castellanza, have supplied the mechanical rolling mill equipment for the new plant, and Asea have supplied the electrical part. The main motors and the transformers were manufactured by the Asea licensee in Italy, Società Nazionale delle Officine di Savigliano, Turin.

Fig. 2 shows a general view of the rolling mill. The heating furnaces for the billets, and the roughing mill, can be seen in the foreground, while the intermediate, looping and rod mills, as well as the cooling bed, can be seen in the background.

The roughing mill consists of three stands driven by a common motor. The tilting table and the roller tables in the roughing mill can be operated either manually or entirely automatically. In the case of automatic operation, photocells transmit information as to the position of the bar to a relay station from which the various movements are controlled. The transverse movement of the bar is arranged by means of a number of guides.

The intermediate mill consists of three two-high stands with common driving machinery. Between the stands there are loop tables and repeaters.

The looping mill consists of four separately driven, alternating two-high stands with horizontal loops between the stands. The roll stands in the looping mill and in the rod mill are of pre-stressed type. Of the eigh loops in the looping mill, three are electrically regulated The loop regulators are located above the loop table and indicate the position of the loops photo-electricall without any mechanical contact with the bar (see Ase Journal 33(1960):6, pp. 89–92). The information fron the loop regulators controls the speed of the motors s



1 Main motor for the roughing mill, 1,500 h.p., 742 r/m, 5 kV, 50 c/s
2 Three-stand roughing mill
3 Contactor-operated automatic slip regulator for roughing-mill motor
4 Shears
5 Main motor for intermediate mill, 1,000 h.p., 450–1,000 r/m, 600 V, d.c.
6 Three-stand intermediate mill
7 Pinch rolls
8 Main motors for looping mill, 350 h.p., 455–1,000 r/m, 600 V, d.c.
9 Four-stand looping mill
10 Asea loop regulators
11 Double motors for the stands 1–4 in continuous rod mill, each rated at 150 h.p., 900–1,500 r/m, 600 V, d.c.
12 Horizontal stands in continuous rod mill
13 Motors for the stands 5–6 in continuous rod mill, 150 h.p., 900–1,500 r/m, 600 V, d.c.
14 Vertical stands in continuous rod mill
15 Coilers, 65 h.p., 1,250 r/m, 440 V, d.c.
16 Cooling bed
17 Metal-clad switchgear
18 Main control board
19 D.C. switchboard
20 Anode reactors
21 Rectifier cubicles
22 High-voltage switchgear
23 380 V control board

Fig. 3. The lay-out of the Nazionale Cogne rod-rolling mill at Aosta, Italy.

that virtually constant loop lengths can be maintained throughout the rolling operation.

The cover illustration, which was taken with a very long exposure time, shows the loops in the looping mill and demonstrates the difference in loop increase between the regulated and unregulated loops.

To obtain rod in lengths, the output from the looping mill can be taken directly to the cooling bed, which is of conventional type. If coils are required, the rod can be coiled in the coilers placed after the continuous wire rod mill. If smaller sections are desired, the rod can be directed from the looping mill to the continuous mill where further reduction takes place.

The continuous rod mill has a design which is somewhat different from that usual for rod mills for special steels. The roll stands have been arranged in a straight line with the loops hanging freely between the stands (Fig. 8).

In rolling mills where one motor drives two stands, the increase in loop size must be regulated by means of mechanical calibration which means that, to some extent, the demands for close tolerances must be dispensed with. Nazionale Cogne have therefore selected the alternative making use of individually driven two-high stands in the rod mill. This arrangement also increases the flexibility of the mill and allows of a more rapid transition from one programme to another.

The continuous rod mill consists of six stands, three horizontal and three vertical. The mechanical equipment used for guiding the rod is extremely simple. When the rod enters the mill, it is guided from one stand to the next in a closed channel, the bottom of which rapidly opens as soon as the rod has entered the next stand. The electric loop regulation adjusts the loop so that it remains at a constant length, which is of great importance since it eliminates variations in the tensile stress to which the rod is subjected. Because of the accurate loop regulation and the very small amount of elasticity in the pre-stressed roll stands, the tolerances of the rod can be kept within very narrow limits. It may be worth noting that the variations in the diameter of the rod for a complete coil (1,250 m) are less than 0.04 mm.

The mechanical and electrical reliability of the rod mill has proved to be extremely satisfactory. These remarks also apply to the other parts of the mill.

From the rod mill, the rod passes through pinch rolls to the pouring coilers. The coils are then automatically lifted up from the coilers on to a conveyor belt and then on to a hook conveyor for cooling and transport to the store. Fig. 4 shows the three coilers.

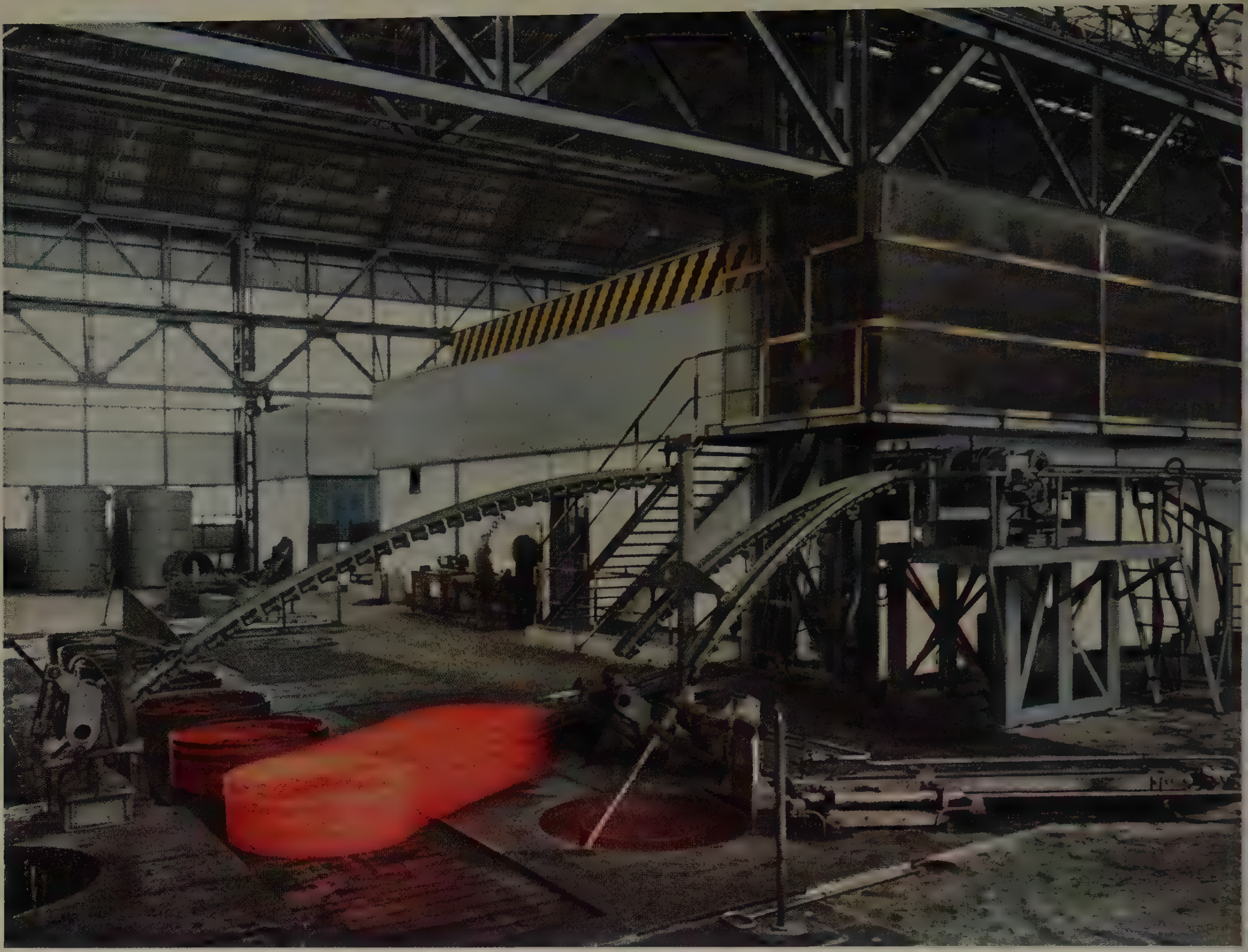


Fig. 4. A pouring coiler in action. A finished coil has just been moved to the conveyor belt. (F 567)

THE ELECTRICAL EQUIPMENT

As mentioned previously, the electrical equipment was supplied by Asea in collaboration with Messrs. Savigliano who manufactured the main motors and transformers under license from Asea. With the exception of the roughing mill, all the roll stands, coilers, shears and pinch rolls are driven by d.c. motors.

The roughing mill is driven by a 1,500 h.p. slip-ring induction motor. It is directly connected to a gear with two flywheels mounted on the high-speed shaft. The secondary resistor of the induction motor is of contactor type and is automatically regulated in accordance with the adjustable maximum motor current. By this means, unnecessary load peaks on the supply network, arising from the brief, but heavy, passes in the first stand, are avoided.

All the other rolling-mill motors and the motors for the pinch rolls and the shears are fed from three rectifier groups. Each group consists of one rectifier transformer and three 6-anode mercury-arc rectifiers. Normally, rectifier group 1 feeds the intermediate mill, group 2 the motors in the looping mill and the motors for the shears and pinch rolls, while group 3 feeds all motors in the continuous rod mill. The three rectifier groups are electrically separate and thus cannot work in parallel. However, the busbar system is so designed that the different motor groups can be fed from any of the rectifier groups, which means that service can be maintained to a limited extent even if one rectifier group should fail.

The rectifier transformers, which have a primary voltage of 5 kV and a maximum secondary voltage of 600 V, are provided with on-load tap changers which permit the secondary voltage to be varied in 19 steps from 600 V to 415 V, and by D/Y reconnection down to a minimum of 240 V.

The voltage variations on the internal 5 kV network are sometimes rather large since six arc furnaces are connected to it. To avoid disturbances on the d.c. network, with resultant interference in the speed regulation, the voltage of the rectifiers is regulated by means of grid control.

When starting the motors, the rectifier voltage is reduced to 6 V and then starting is smoothly carried out by linearly increasing the voltage up to the set transformer voltage.

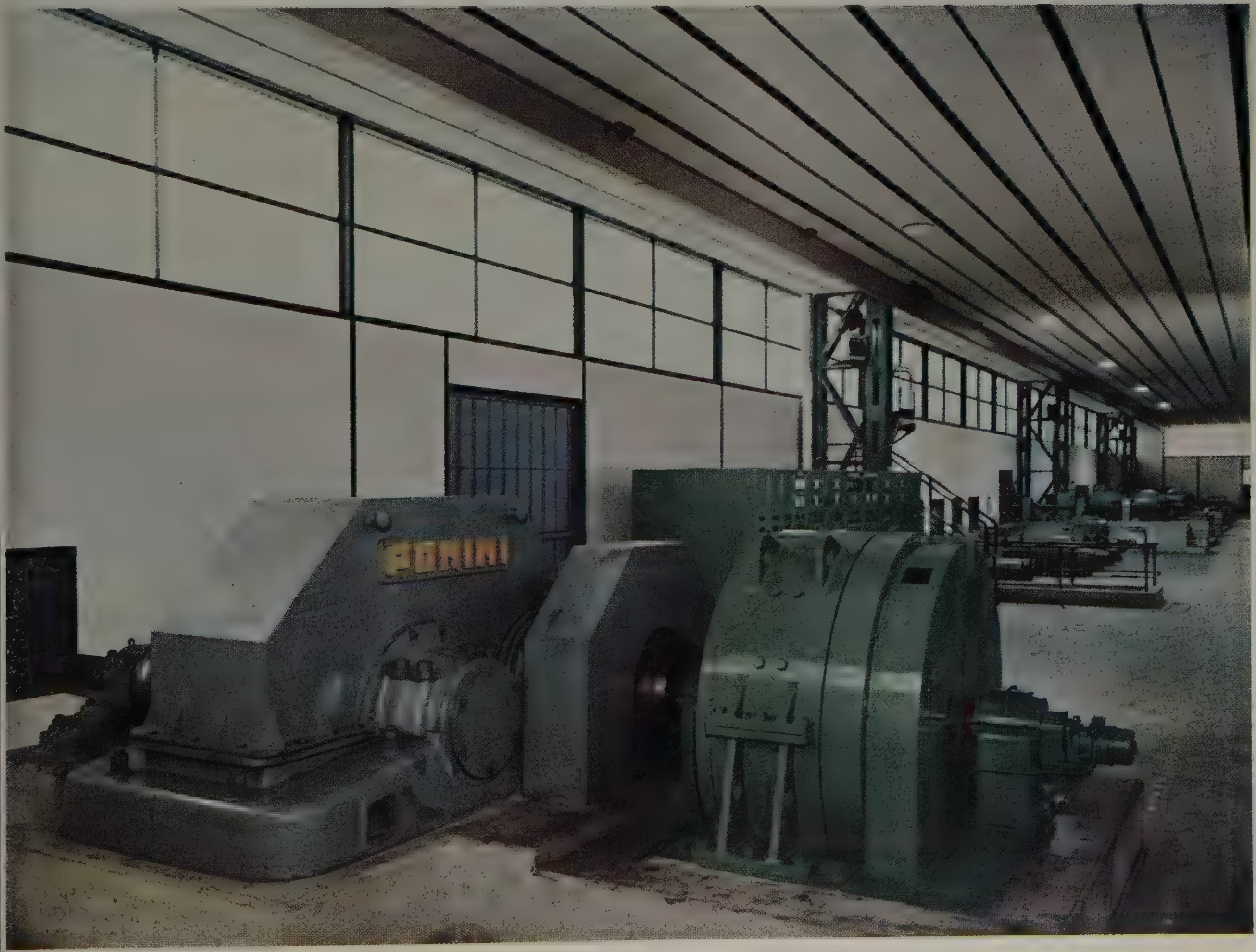
Fig. 5 shows the large machine room. The driving machinery for the intermediate mill can be seen in the foreground, and, further back, the four looping-mill motors.

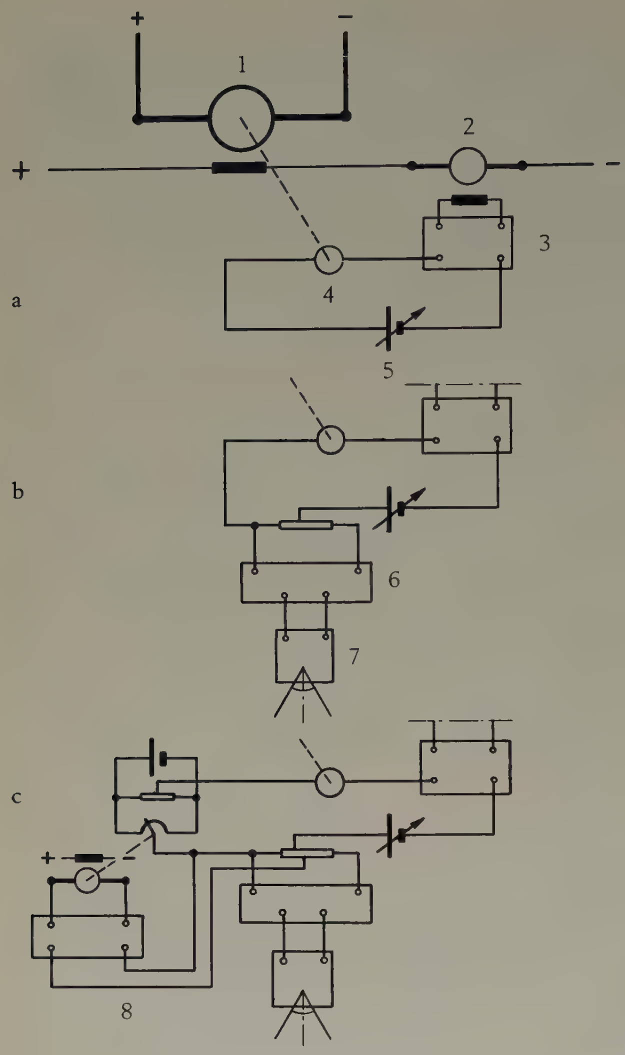
In rolling mills for the production of high-quality steel, the very highest demands are made on the rapidity and accuracy of the speed regulation. The rod must pass through the entire rolling mill without being stretched, necessitating the formation of loops between one stand and the next. To avoid excessive cooling, the loop length must be as short as possible. Particularly in the continuous rod mill where the speed of the rod in the last stand is more than 70 km/h (4,000 ft/min) and where the loop length must be regulated with an accuracy of ±10 cm (4 in.), accurate speed regulation is indispensable. As an example, it may be mentioned that a speed error of 1 per cent reduces a loop from the normal length of 40 cm (16 in.) to 0 cm, in less than two seconds, with consequent stretching of the rod. It may therefore be of the interest to describe how regulation takes place.

Fig. 6 shows a simplified diagram of the regulation circuit. As previously mentioned, the rectifier voltage can be varied within the range 240–600 V. The most suitable voltage level can be selected for each rolling programme. The speed of the individual motors is then controlled by means of field regulation. The field winding of the motor is connected, in series with a booster exciter, to a constant direct voltage, and variations in the field current are brought about by changing the excitation, and hence the output voltage, of the booster exciter. The latter is controlled by push-pull-connected transductor amplifiers, the output voltage of which is determined by the current strength in the control winding. In the steady-state condition, the tachometer-generator voltage is opposed to, and virtually equal to, the reference voltage, resulting in zero control current.

If, for example, the motor speed falls while the reference voltage remains the same, the equilibrium in the control circuit is disturbed and a control current is obtained which affects the transductor and consequently the booster exciter in such a way that the motor field current is reduced, whereupon the motor speed in-

Fig. 5. View of the machine room showing, in the foreground, the drive for the intermediate mill and, in the background, the motors for the looping mill and the continuous rod mill. (F 566)





1 Main motor
2 Impulse exciter
3 Transductor amplifier
4 Tachometer generator
5 Reference voltage
6 Thyratron amplifier
7 Loop regulator
8 Transductor amplifier

Fig. 6. Simplified diagram of the regulating circuits for the Asea loop regulators. (Fr 1204)

creases and equilibrium is restored. The motor speed can be selected by varying the reference voltage.

The individual speed regulation as outlined above keeps the motor speed virtually constant irrespective of variations in the load. However, the fact that the ratio between the outgoing speed of the rod from a stand and the peripheral speed of the rolls is not constant, but varies with the temperature of the rod, makes necessary the supplementing of the speed-regulation system.

The movement of the loop between two stands indicates how the individual speeds of the stands correspond to each other. By measuring the loop position, and by introducing the measured value into the control circuit, speed regulation is obtained which takes the above-mentioned variations into consideration.

Fig. 7 shows the sensing device of the Asea loop regulator. A description of the regulator is to be found in Asea Journal 33(1960):6, pp. 89–92. The box contains a photocell device, sensitive to infra-red radiation, which senses the position of the loop and produces an output voltage, the polarity and amplitude of which are proportional to the deviation of the loop from its normal position. The output from the photocell is amplified in a thyratron amplifier and introduced into the control circuit as shown in Fig. 6b.

All six motors in the continuous rod mill, and three motors in the looping mill, are fitted with loop-regulation equipment. The speed of the fourth stand in the looping mill is constant and regulation is "forwards" in the continuous rod mill and "backwards" in the looping mill. This means that the loop regulator in the continuous mill controls the speed of the following stand, and, in the looping mill, the speed of the preceding stand.

In the rod mill, greater demands are made on regulation than in the looping mill. For this reason, in the former, the loop-regulation equipment is supplemented by a device which automatically corrects the loop position with reference to temperature variations, roll wear, etc. (see Fig. 6c). The criterion for the most suitable loop position is that the voltage from the loop regulator should be zero. While this voltage directly regulates the motor speed extremely rapidly, it also, via a transductor amplifier and a slow-running motor-operated device, resets the reference voltage for the basic speed as soon as the voltage from the loop indicator begins to deviate from zero.

This additional regulation means that the rolling mill automatically sets itself at the correct motor speed even though, when going over to a new rolling programme,

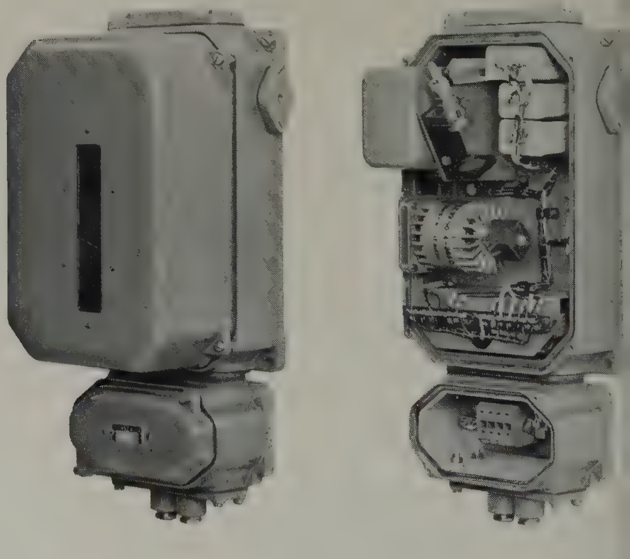


Fig. 7. The photocell device of the Asea loop regulator. (51904, 51905)

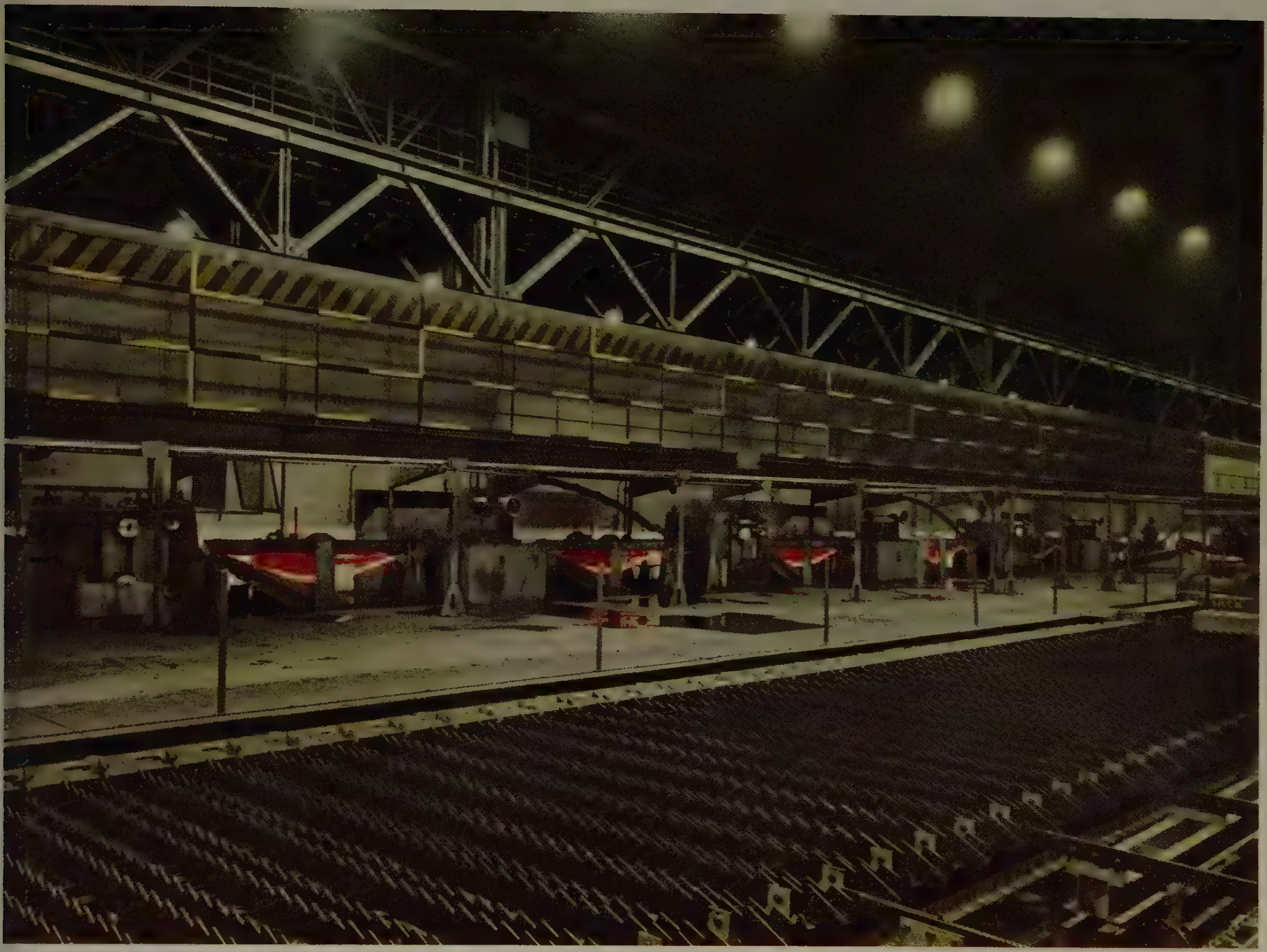


Fig. 8. View of the six-stand continuous wire-rod mill. The six vertical loops are controlled by Asea loop regulators. The cooling bed can be seen in the foreground. (F 568)

or after changing rolls, it should happen that the speed has been incorrectly set. After changing a rolling programme at the Nazionale Cogne Works at Aosta, the speed is set so that the rod is stretched between the stands. The loop regulation intervenes and then adjusts the motor speed so that, a moment later, all the loops are at the correct level. By this means, material wastage is avoided.

Fig. 8 shows the loops in the rod mill. The film has been exposed during the rolling of an entire rod. The photograph shows how accurately the loop regulator works. The red area was coloured when the loop was formed and the "thickness" of the bright loop shows at a glance the accuracy of regulation of the equipment.

The speed of the pinch rolls before the looping mill is so regulated as to follow the speed of the intermediate mill. In the same way, the speed of the pinch rolls before the coilers is regulated so as to follow the speed of the stand actually supplying the wire. The regulation of the pinch rolls is a combination of speed, and current-limit, regulation, so arranged that the pinch rolls at no-load adjust their speed to that of the roll stands in question, and when under full load work at a constant torque.

Since the coiler motors have to be able to start and stop individually, each is fed by its own generator. Therefore, complete regulation is brought about by means of varying the generator voltage. During coiling, the speed is regulated in relation to the outgoing speed of the rod and the load is then quite insignificant. During acceleration and retardation, current-limiting regulation intervenes and, in order to reduce the time taken for the above operations, the current limit can very well be set somewhat higher than the rated current of the coiler motor.

It might be thought that a relatively complicated regulation equipment of this kind would reduce the service reliability of the rolling mill and that it would call for highly qualified service personnel. However, experience gained at Cogne and at other similar plants shows that this is not the case. Where possible, Asea use transductor amplifiers in regulation systems for industrial, and power, plants. Although, in recent years, electronic valves have developed considerably and be-

HONORARY DOCTORATES FOR ÅKE VRETHEM AND HALVARD LIANDER

On the 11th June, an honorary doctorate in technology was conferred on the Managing Director of Asea, Åke Vrethem, at Chalmers Institute of Technology, Gothenburg. On 31st May, the honorary degree of Doctor of Philosophy was conferred on the Deputy Managing Director, Halvard Liander, at Uppsala University.

In Sweden, honorary doctorates at the institutes of technology have on occasions been conferred on persons who have distinguished themselves by outstanding individual contributions to engineering, as well as on persons in leading positions who, with great understanding of the potentialities and requirements of engineering techniques, have stimulated and promoted the advancement of engineering science.

Åke Vrethem

Halvard Liander

As far as Dr Vrethem is concerned, both these categories apply. As head of the Electrotechnical Department of the Swedish State Power Board during an active period of creative work in the sphere of high-power transmission, he not only made bold decisions on the adoption of new techniques, but he also personally carried out research and investigational work especially in the field of insulation and over-voltage protection. The basic experience he gained there has indubitably contributed to his strong sense of the importance of technical development work which he has later displayed as the head of Asea.

Dr Liander has, throughout all his activities, been in close touch with technical research, amongst other things as the head of the Asea Materials Laboratory for 12 years, before he took over his present post as head of Design and Development. Like Dr Vrethem, he studied at the Royal Institute of Technology in Stockholm, although as a chemist, which fact is remarkable both as an indication of the great importance of chemistry and materials technology to the development of electrical engineering, and of Dr Liander's breadth of scope as an engineer. At a time when research and education in the natural sciences at the Universities and their relation to a country's industrial and general material development is such an important current question, the conferring of an honorary doctorate by the Mathematics and Natural Science Faculty of Uppsala University on an engineer and active industrialist is an event of particular interest.

The colleagues and associates of the two new doctors are happy to pass on – as an echo of the two-gun salutes fired in their honour at the ceremonies in Gothenburg and Uppsala – this news to friends in all parts of the world.

Uno Lamm

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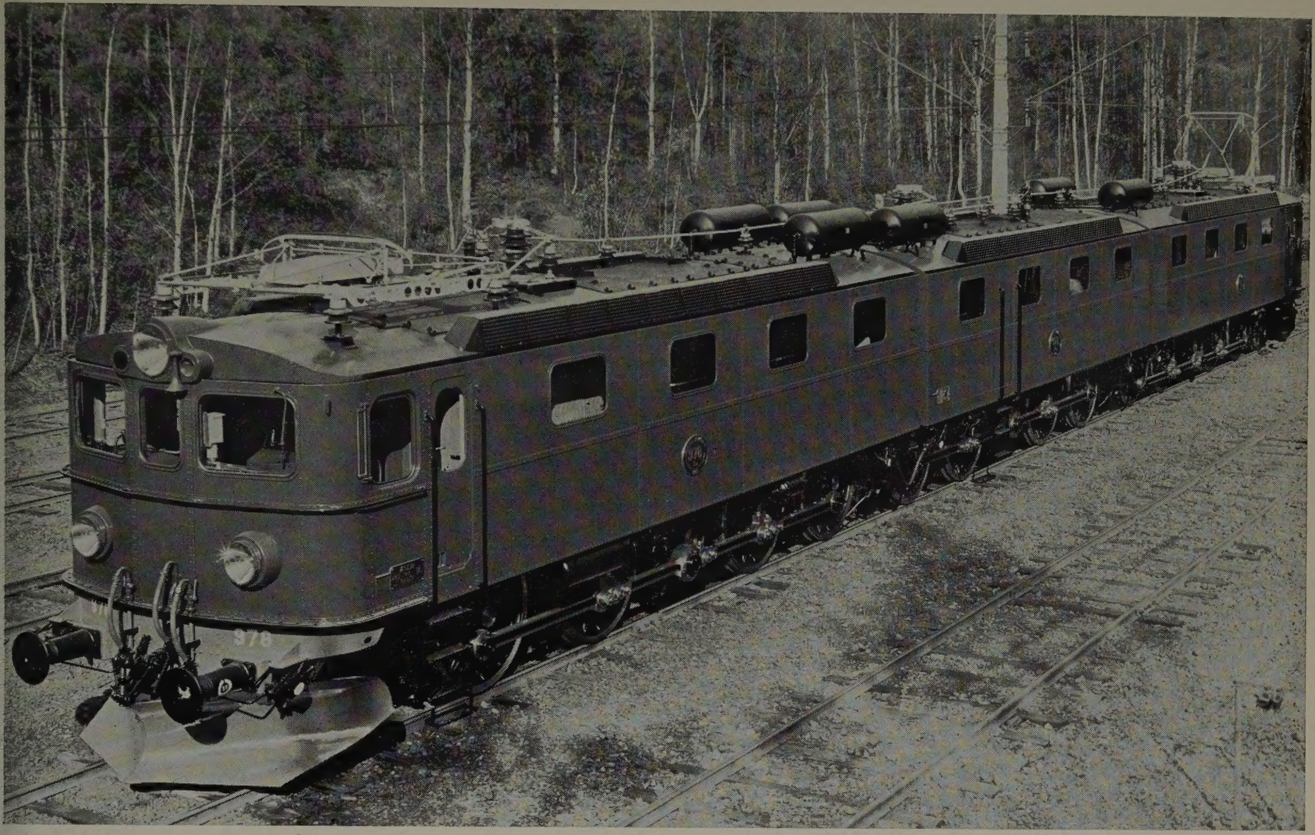
come more reliable, the risk of disturbances in an electronic-valve system still remains. In systems of this kind, currents, considerably lower than those in a transductor system, are used and the risk of inductive and capacitive disturbances from adjacent high-current and high-voltage circuits is considerably greater than for the electrically more robust transductor system. Experience has shown that, once a regulating system making use of transductors has been adjusted, no further measures are needed. The transductor characteristics do not change with time, and, practically speaking, only mechanical damage can cause disturbances in a properly designed regulating system of this kind.

Experience of the reliability of the loop regulator is equally positive. As mentioned previously, the regulator works without any mechanical contact with the hot rod, and, apart from a rotating mirror driven by a synchronous motor, it contains no moving parts.

The first part of the electrical equipment for the new rolling mill was supplied in August, 1958. Erection at the site, which was carried out by the customer's own staff, was started at the same time. In October, 1958, the roughing mill was taken into service and all erection work was completed by April, 1959 when all the machines were test run.



(55250)

NEWS IN BRIEF

ONE OF THE MOST POWERFUL ELECTRIC LOCOMOTIVES IN THE WORLD

When the Swedish State Railways, in July, 1958, ordered the first articulated locomotive with three sections for the ore line in northern Sweden, this type of locomotive was stated to be the most powerful in the world. By this the tractive effort of the locomotive was intended; the comparison excluded gas-turbine electric locomotives and converter locomotives with three-phase motors such as were manufactured in America in the 1920's. If, however, the horse-power rating is taken as a yardstick, a double locomotive manufactured in Switzerland in 1939 has held the record. The locomotive has now been rebuilt as two single locomotives. It was described at the time as "the most powerful locomotive in the world", but as it was geared for high speeds its tractive effort was considerably less than that of the Swedish Dm 3 locomotive. Whatever yardstick is used, however, any comparison is of doubtful value. Even the definition of what constitutes *one* locomotive as opposed to several units coupled together may give rise to difficulties. However, it cannot be denied that the Dm 3 locomotive is one of the most powerful electric locomotives in use to-day.

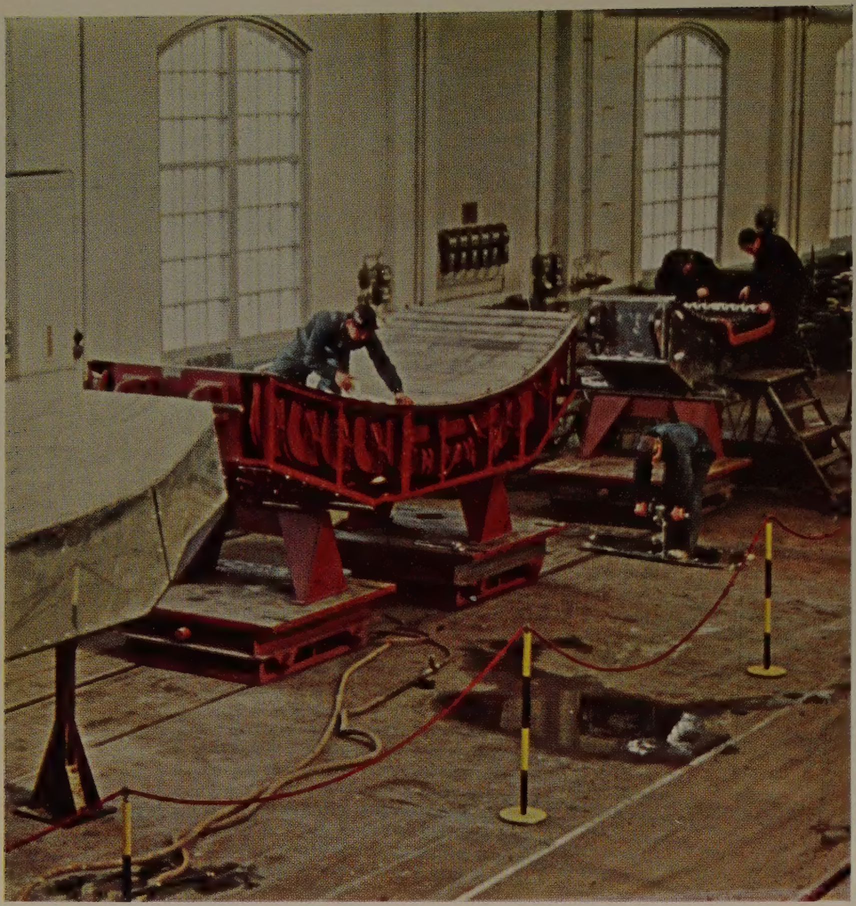
The transport capacity of the northern part of the Swedish ore line started to become inadequate as early as 50 years ago. Electrification approximately doubled its capacity, and this was achieved without having to adopt double tracks. Since then, its capacity has increased at the same pace as larger locomotives have been put into service, and the heaviest trains hitherto (3,200 tons) are hauled by double-articulated Dm locomotives with a maximum tractive effort of 53 tons (at the circumference of the wheel), see Asea Journal 30(1957):11–12, pp. 152–156.

By inserting yet another section between the two sections of the double-articulated locomotive, the tractive effort has been increased by 50 per cent (the maximum effort being about 80 tons). As previously, this means a corresponding increase in the capacity of the entire line. However, the strength of the couplings has already reached its limit. Further, the capacity of the waggons is no longer thought to be adequate and they must be adapted to the more powerful locomotives before these latter can be fully utilised. Thus, when these new waggons are all in service, the traffic capacity of the ore line will again be increased by about 50 per cent and the double-track alternative can once more be left to the future.

The three locomotives in the series which have now been delivered consist of three permanently coupled parts which are similar except that the central section has no driver's cabins, no pantograph and no pony axle. The locomotive has, in all, two pantographs, three main circuit-breakers, three main transformers and three contactor equipments for voltage regulation. Since each third has two traction motors and four driven axles, the locomotive has, in all, six motors and 12 driven axles. The axle load is about 19 tons and the total adhesion weight about 230 tons; the weight of the locomotive is about 260 tons. The overall length of the locomotive is 35.25 m, the maximum tractive effort (4,500 A/motor) is 79.5 tons and the maximum speed 75 km/h (47 m.p.h.). Further information is given in the above-mentioned article in the Asea Journal.

This locomotive, as is the case with all electric locomotives on the Swedish State Railways, has been supplied by Asea which, in the normal way, has made use of the services of AB Svenska Järnvägsverkstäderna, AB Motala Verkstad and Nydqvist & Holm AB for the mechanical parts.

Asea Reg. 6132



THE LINE PRODUCTION OF INDUCTION STIRRERS FOR ARC FURNACES

The considerable present-day demand for high-quality steel has meant rapid development of steelworks producing electric steel, at the same time as demands on the strength and purity of the steel have continually increased. In this connection, the Asea induction stirrer has proved to be an ideal instrument for the rapid and reliable manufacture of high-quality steel with close analysis tolerances, see Asea Journal 32(1959):10–11, pp. 147–156. With the aid of the stirrer, it is now possible, even in very large arc furnaces, to manufacture those special steels which previously caused difficulties even in the smallest furnace units.

The induction stirrer patented by Asea is now manufactured rationally in accordance with the conveyor-belt principle in a special factory in Västerås.

At present, work is going on for deliveries to customers in the U.S.A., Western Germany, Japan, Poland, Czecho-Slovakia, Italy and Sweden. Asea Reg. 663

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One of the most powerful electric locomotives in the world

The line production of induction stirrers for arc furnaces

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